HANDBOOK OF RESEARCH ON SCIENCE EDUCATION

VOLUME II

EDITED BY
NORMAN G. LEDERMAN
SANDRA K. ABELL

ROUTLEDGE

Handbook of Research on Science Education

Building on the foundation set in Volume I—a landmark synthesis of research in the field—Volume II is a comprehensive, state-of-the-art new volume highlighting new and emerging research perspectives.

Features of Volume II

- International range of authors who are the most prominent scholars in the field
- Overarching attention to research paradigms and their relationship to learning theory, research design, data collection, data analysis
- Coverage of both global issues (such as policy) and the teaching and learning of specific disciplines
- Balanced treatment of research on teaching and research on learning

The contributors, all experts in their research areas, represent the international and gender diversity in the science education research community. The volume is organized around six themes: theory and methods of science education research; science learning; culture, gender, and society and science learning; science teaching; curriculum and assessment in science; and science teacher education. Each chapter presents an integrative review of the research on the topic it addresses—pulling together the existing research, working to understand the historical trends and patterns in that body of scholarship, describing how the issue is conceptualized within the literature, how methods and theories have shaped the outcomes of the research, and where the strengths, weaknesses, and gaps are in the literature.

Providing guidance to science education faculty and graduate students and leading to new insights and directions for future research, the *Handbook of Research on Science Education,* Volume II is an essential resource for the entire science education community.

Norman G. Lederman is Professor and Chair, Department of Mathematics and Science Education, Illinois Institute of Technology, USA.

Sandra K. Abell (deceased) was MU Curators Professor of Science Education, University of Missouri, USA. A renowned researcher and author nationally and internationally, she was named a fellow of the American Association for the Advancement of Science (AAAS), the American Educational Research Association (AERA), and the National Science Teachers Association (NSTA) and received numerous awards for her teaching and mentoring of students.

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Volume II

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Norman G. Lederman

Sandra K. Abell

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Dedication

Volume I of this *Handbook* grew from conversations between Sandi and Naomi Silverman, who at that time was at Lawrence Erlbaum Associates, Inc. Sandi then reached out to me to serve as a co-editor. Sandi's influence on the research preceding and following the publication of Volume I was strong and continues to be as strong and visionary as ever. Consequently, it would be a crime not to include Sandi as co-editor for Volume II. Sandi and I were already discussing this new volume prior to the time of her unfortunate passing. Throughout Sandi's career, she was an excellent scholar in the area of teacher education, among other areas, a strong mentor (I think one of her PhD students described her as the master of tough love), global leader in science education, and a role model for us all. She had the perfect balance of theory and practice that many of us only aspire to develop. Personally, I always respected Sandi's work, but I also could always rely on her honesty and integrity when it related to my work and a wide variety of other professional and personal topics. I miss Sandi greatly, and it is my sincerest hope that Volume II of the *Handbook of Research on Science Education* will help continue her legacy, not that her legacy needs any additional help. We miss you, Sandi!!

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Preface

This volume builds on the foundation presented in Volume I. Volume I will remain in print, as what is provided here builds on but does not simply repeat what was previously published. This volume consists of updated chapters from Volume I. These chapters are not repetitions of previous chapters, and overlap only exists where necessary to understand current and emerging trends in the field. Most of the chapters have been written by chapter authors from the previous volume, but some new authors have also been included. Since the publication of Volume I, Taylor & Francis and I have been surveying members of the science education community about topics omitted from Volume I or those topics needing expansion or reduction. In response, this volume also includes numerous chapters, written by prominent scholars, on topics of critical importance to researchers and theoreticians in science education.

As with Volume I, the contributors to this volume are experts in their research areas and represent the international and gender diversity in the science education research community. The volume is organized around six themes: theory and methods of science education research; science learning; diversity and equity in science learning; science teaching; curriculum and assessment in science; and science teacher education. Each chapter presents an integrative review of the research on the topic it addresses—pulling together the existing research, working to understand the historical trends and patterns in that body of scholarship, and describing how the issue is conceptualized within the literature, how methods and theories have shaped the outcomes of the research, and where the strengths, weaknesses, and gaps are in the literature.

Each of the aforementioned sections was organized and monitored by a section editor prominent in the field, who reviewed each manuscript and integrated the evaluations by at least two external reviewers. Finally, the overall sets of chapters were reviewed by myself as the primary editor for the *Handbook*. To this end, the compilations of chapters were thoroughly peer reviewed.

Since the publication of Volume I, research on teaching and learning in science has remained a highly active area of study. Our continued quest to improve science teaching and learning has been further fueled, in recent years, by the proliferation of international comparisons and the emergence of numerous standards for teaching and learning throughout the world. The primary goal continues to be scientific literacy, but how this construct is defined has been changing, and perspectives on how it is achieved are equally varied. The continued emergence of the learning sciences has altered researchers' perspectives on the interpretation of classroom practice, classroom environments, and student learning. This is reflected in the expanded section on Science Learning edited by **Richard Lehrer**.

In-depth discussions of theory and methods of science education research were not provided in the previous volume. A separate section, edited by **David F. Treagust**, on these perspectives has been added as the opening section to the *Handbook* in an effort to create an overall perspective from which to interpret what follows. The section addresses both qualitative and quantitative perspectives, and there is no intended prominence or favor given to one approach versus another. There is intentionally not a separate chapter on mixed-methods research, but the authors of both the qualitative and quantitative chapters have addressed the mixed-methods perspective.

In response to reviewers and growing emphasis within the science education community, the section on diversity and equity in science learning, under the editorship of **Cory A. Buxton and Okhee Lee**, has been significantly expanded and enhanced. In particular, much more attention is given to indigenous knowledge and English language learners. A separate chapter on inquiry teaching has been added to the science teaching section, which is edited by **Jan H. van Driel**. In addition, there are now new chapters in the curriculum and assessment in science section, edited by **Paul Black**, on socioscientific issues and precollege engineering education. The section on science teacher education, edited by **J. John Loughran**, primarily consists of enhanced and updated chapters from Volume I. As you would expect, the emphasis on the nature and development of pedagogical content knowledge remains a strong theme.

At the end of the Preface for the previous *Handbook*, Sandi and I included a section titled "The Future of Science Education." In this section, we provided some suggested guidelines for researchers to consider related to our overall purpose of improving teaching and learning, keeping an open mind with respect to alternative theoretical perspectives, grounding our research in the *real world*, and communicating our research to teachers. The two former guidelines need not be repeated here, but I would like to return to the latter two. I think Sandi would agree with this decision.

Science education and education in general is an applied field. I know some would like to hold on to the importance of theoretical research that may or may not have applications in the future. After all, some research that seems quite theoretical now may be of practical use in a decade. Realistically speaking (given the constraints within which we operate and the mandate of the public), somewhere along the way our research and our research-derived suggestions must be grounded in the *real world* of teachers and students. Our research must address the concerns of teachers and students, and it must be applicable in our school systems and society. To have any warrant, our research must address questions of educational importance. Each chapter contains a section addressing the implications of its topic. We need to think carefully about the meaning of these sections and not let them fall into the category of an article section that must be included. We continue to have a problem with the gap between research and practice. I have heard this since I was a PhD student. We need to work more on communicating our research to teachers and policy makers. All too often, our meetings and journals are set up so we are only speaking with other researchers. On a personal level, when I attend National Association for Research in Science Teaching or other research meetings and present my work on nature of science, the audience is very interested in my research design, data analysis, and conclusions, and there is very little interest in or time to discuss how I actually teach people about nature of science. When I attend NSTA or other practitioner-oriented meetings, the audience is primarily interested in what I actually do with students and teachers and not as interested in the specifics of research design and data analysis. You certainly notice a similar pattern in articles printed in "teacher" journals and "researcher" journals. The problem is multifaceted, but we must continue to work on communicating our research to teachers. It is our responsibility.

This *Handbook of Research on Science Education* is written for researchers, and it will be read almost exclusively by researchers. It would not be the best choice for a preservice or inservice teaching strategies course. We need to make the conscious effort to translate what is presented in the pages of this *Handbook* into a form that is readily understandable and usable by teachers, with the ultimate goal of helping their students. It is not often talked about, but we must work on developing our pedagogical content knowledge for teacher education.

Acknowledgments

Serving as a volume editor can be as labor intensive as one wants to make it. However, there is always a variety of important tasks that would not be completed without significant help. I want to thank Dionysius Gnanakkan, research assistant at Illinois Institute of Technology, for all his help related to substantive editing, clerical editing, formatting of chapters, and the development and application of the *Handbook* database. Because of Dion's extensive knowledge of science education and science education research, his assistance exceeded what could be expected from a general editor. This *Handbook* could not have come to fruition without his help. I hope he doesn't graduate too soon!

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Section I

Theory and Methods of Science Education Research

Section Editor: David F. Treagust

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Paradigms in Science Education Research

David F. Treagust, Mihye Won, and Reinders Duit

Why Discuss Research Paradigms?

From the nature of science studies, science education researchers are familiar with Thomas Kuhn's (1962) theory of paradigm shifts. Kuhn's main focus was on scientific inquiry and the scientific community, not on social or educational research, but his term "paradigm" provides a convenient reference point to talk about different sets of beliefs, values, and methodologies in educational research (Schwandt, 2001). A paradigm in educational research is recognized as a worldview that sets the value of research and asks such questions as (Guba & Lincoln, 1994): What is counted as social knowledge, action, and meaning? What are the main goals of educational research? What are the roles of educational researchers? How do we carry out our research projects? As Anderson (1998) notes, "How you see the world is largely a function of where you view it from" (p. 3). Consequently, the research paradigms guide the researchers throughout the empirical research process, from setting the research purpose to selecting data collection methods to analyzing the data and reporting the findings.

Despite their importance, research paradigms are rather hidden from plain view, especially for novice educational researchers. Many introductory research methods books do not extensively talk about research paradigms and philosophical backgrounds, except for the procedural differences between quantitative and qualitative research (Creswell, 2012; Fraenkel, Wallen, & Hyun, 2012; Punch, 2005; Wiersma & Jurs, 2005). Rather, they focus on "practical" aspects of data collection and analysis—that is, step-by-step how-to procedures, such as how to phrase survey questions, how to use statistical packages, or how to conduct effective interviews. In such discussions of the research process, educational researchers view their studies mainly in terms of technicalities, without recognizing the worldviews that shape and validate their knowledge claims (Kincheloe & Tobin, 2009). The fact that many people conduct studies without seriously considering research paradigms may be interpreted as the practical aspects of identifying a research paradigm not being as paramount as some researchers believe (Bryman, 2008). Some researchers even regard discussion of paradigms as a purely philosophical exercise, a remnant of the paradigm wars in the 1980s and 1990s (Morgan, 2007). A seminal article published by Gage (1989, written as though it was 2009) described the situation of the paradigm wars from a vantage point of 20 years hence. As discussed in this article, positivist and post-positivist research flourished in the 1980s and was later challenged by alternative paradigms, namely those of an interpretivist and critical nature. Much of what Gage wrote about has turned out to be what occurred in practice. However, initial antagonism of proponents of one paradigm toward another appears to have been somewhat moderated with the development and use of mixed-methods research (Bryman, 2008) and the wider acknowledgement of the contributions that research from different paradigms brings to the education community (Bredo, 2009).

Nevertheless, in recent years, we have witnessed some heated discussion on the diversity of research paradigms and what it means in the practice of educational research (Moss et al., 2009). Many education philosophers and researchers have found that the education research guidelines and policies published in 2002 in the United States by the National Research Council and by other research funding organizations dogmatically promote a certain type of research studies under the banner of evidence-based, scientific research. These educational authors believe that it is dangerous to have such a limited view on what "other" types of research could contribute to establishing better education. (For more detailed discussion of this issue, please refer to the journals *Educational Researcher* in 2002 [volume 31, issue 8] and 2009 [volume 38, issues 6–7] and *Qualitative Inquiry* in 2004 [volume 10, issue 1].)

Without an analytical understanding of each research paradigm, it is easy to misjudge the quality and the value of research studies and miss the opportunities to learn from them (Moss et al., 2009). In the education community and the science education community in particular, there is a tendency to ignore/dismiss research studies in other research paradigms (Kincheloe & Tobin, 2009). Post-positivists may think that interpretivist studies are anecdotal and not methodically rigorous enough, and critical theory studies are too politically oriented. Interpretivists may regard that post-positivist studies are superficial or limiting. Critical theorists may consider that post-positivist studies are exacerbating educational inequality. Yet there is great need to have an open mind to learn from the differences (Maxwell, 2004; Moss et al., 2009). The philosophical and practical diversity in the education research community not only supports building more balanced knowledge in education (St. Pierre, 2002) but also makes ways for more comprehensive research efforts with common goals (Bredo, 2009).

In this chapter, we outline three research paradigms and describe how each paradigm is realized in various research studies in science education and conclude with a discussion of the pragmatic approaches taken by mixed-methods researchers. This is not an attempt to pin research studies on one category of paradigm or another. Rather, by describing how different paradigms play out in the science education research field, we attempt to reflect on our own research practices and facilitate a dialogue across paradigms among science education researchers. While there are many different categorizations and boundary drawings of research paradigms (Clandinin & Rosiek, 2007; Lincoln & Guba, 2000; Moss et al., 2009; Taylor, Taylor, & Luitel, 2012), we have used the categories of positivist/post-positivist, interpretivist, and critical theory and illustrated the characteristics of each paradigm in relation to one another. We intentionally did not use the common categories of quantitative and qualitative research in this chapter because they could be misleading—as if paradigm is limited to the choice of data collection methods. As mentioned, we believe a research paradigm is much more encompassing than the choice of data types.

Positivist/Post-Positivist Research Paradigm

Philosophical Backgrounds of Positivist Research

Positivism is understood as "any approach that applies scientific method to the study of human action" (Schwandt, 2001, p. 199). Following the empirical science tradition, positivist researchers assert that in order to make a meaningful knowledge claim, research studies should be firmly supported by *logical reasoning and empirical data* that are self-evident and verifiable (Schwandt, 2001). Many science education researchers may find this ideology of positivism familiar because it is well integrated within Western academic culture—such as viewing objective, scientific, logical, evidence-based research as the most desirable form of research (Howe, 2009; Kincheloe & Tobin, 2009). In contemporary discourse, however, positivism carries some negative implications due to its link to naïve realism, and modified forms of positivism are quite prevalent and influential in the education field. Next, we present post-positivism as a variation of positivism (logical empiricism) rather than as a counterpart of positivism.

Different from positivists, post-positivists do admit that our culture, personal value systems, and other surroundings influence our perception of the world in both positive and negative ways (Phillips & Burbules, 2000)—positive because it guides what to look for and how to make a reasonable, logical explanation but negative because it may lead to tunnel vision, limiting our understanding of the phenomenon in the truest form. Because of the negative influence of our prejudices, we cannot be sure whether our knowledge claims really reflect the truth. Yet this does not mean that the truth does not exist or that the truth does not matter. For example, a group of teachers may personally prefer a didactic teaching method based on their experience. Their reluctance to recognize alternative teaching methods, however, does not mean that there could be certain teaching methods that are more effective and yield better outcomes with students. Here, the role of post-positivist researchers is, as objective investigators, to systematically approach the truth as best as they can. Rather than simply relying on prior experiences, the researchers endeavor to collect comprehensive empirical data methodically and compare the different teaching methods objectively. By conducting a systematic empirical inquiry, post-positivist researchers believe that they can reach close to the truth and are able to inform the people of interest (teachers, policy makers, parents, students, etc.) in order to help make wise decisions, for example, on a new educational program or educational improvement plans (in this case, informing teachers which teaching method is better).

Examples of Post-Positivist Research

Similar to research in the natural sciences or psychology, the post-positivist tradition focuses on seeking a scientific causal or at least a correlational explanation—for example, the effectiveness of a new teaching method on students' achievement, the relationship of students' family background and their attitudes toward schooling, or the influence of students' perceptions toward science on their academic performance. Naturally, post-positivist researchers regularly adopt comparative experimental designs or survey designs to find a causal or correlational explanation. To help readers understand the distinct characteristics of post-positivist research, we introduce three research studies from the science education literature.

Kihyun Ryoo and Marcia Linn (2012) followed this post-positivist research tradition and investigated the effectiveness of an educational program in terms of students' conceptual achievement through pre- and posttests. This study resembles much of an experiment report in the natural sciences. The authors conservatively designed their study in advance, strictly followed the research protocols, and methodically elaborated the research procedures in the report to convince the readers that they fulfilled the quality standards of the post-positivist experimental design. At the beginning of their report, they posed their research question, "How do dynamic visualizations, compared to static illustrations, improve middle school students' understanding of energy transformation in photosynthesis?" The researchers divided students into an experimental group with dynamic visualization and one control group with static visualization. While the researchers did put the effort in making the experimental education program attractive (in this case, dynamic visualization), they tried to make the control and experimental conditions similar as much as possible, except for the instruction materials (that is, independent variable of dynamic versus static visualization). To equalize those two conditions, the researchers adopted a few measures: they selected two teachers with similar teaching experience (5 years); within each teacher's class, the students were randomly assigned to two groups after a pretest; the students went through identical lessons and assessments except for the visualization modes; and the number of students was large enough to make analytical claims based on statistics (200 students in total). After the lesson and assessments, the researchers categorized the students' written answers based on an assessment rubric to decide on the improvements of students' understanding of the concept. Once the data were in, the researchers used a set of statistical packages to analyze the data and backed up their research findings using various sources of data and triangulation. In order to convince the reader that procedures had been followed faithfully, the researchers provided an extensive explanation of the research procedures with statistical significance, internal validity, and external validity of the study. After the data analysis, the researchers informed the readers of the educational implications of the findings and the limitations of the study, such as where the results can and cannot be generalized to and possible ways to increase the educational effects for further studies.

Another post-positivist study by Sunitadevi Velayutham, Jill Aldridge, and Barry J. Fraser (2011) examined the affective domain. The researchers developed a survey instrument to measure students' motivation and self-regulation in science learning. Based on a literature review, the researchers identified a few key components that reportedly influence students' motivation in science learning, such as learning goal orientation, task value, self-efficacy, and self-regulation. Here, we notice the researchers' firm belief that extensive utilization of previous research studies is the effective way to make a reliable instrument to measure students' perception of themselves (Jaeger, 1997). They painstakingly identified the possible factors and wrote the questionnaire items, because the wording of the questions is regarded as being very important to obtaining the corresponding response. They conducted a pilot study and interviewed some teachers and students. The interviews were not a substantial part of the study but were used to check whether students' responses in the survey matched with what they said in their interviews. After the confirmation, the researchers distributed the survey to a large number of students (1,360 students in 78 classes). The students were the data source, and any personal connection with them was neither necessary nor desirable to make an unbiased, scientific claim. After the data collection, the researchers ran a series of statistical analyses to validate the instrument. With the numbers neatly organized in a table format, the researchers methodically claimed that their survey instrument has internal consistency reliability, concurrent validity, and predictive validity. They also claimed that they took stringent measures to safeguard themselves against methodical biases during their study. The researchers concluded the report with possible uses of the instrument for future studies.

Another research domain that lends itself to a post-positivist research paradigm includes studies that assess national standards or competencies of learning. National standards have been introduced worldwide (Waddington, Nentwig, & Schanze, 2007) and, for the evaluation of these standards, quantitative measures have been developed and evaluated for the various competencies addressed (DeBoer, 2011). These competencies include understanding and application of science concepts, principles and views of the nature of science, and also the competences to evaluate and judge the role of science knowledge in understanding key problems of society and lifeworld. In Germany, Julia Holstenbach, Hans Fischer, Alexander Kauertz, Jürgen Mayer, Elke Sumfleth, and Maik Walpuski (2011) developed a model of these competencies that is theoretically based and empirically validated by a test composed of items allowing large-scale assessment. The model includes the following areas of competence: (1) science knowledge, (2) knowledge about science, (3) communication, and (4) evaluation and judgment. The work draws on earlier work on evaluation and judgment competence in the field of biology education by Eggert and Bögeholz (2006), who presented a theoretically based competence model for decision making in the area of sustainable development. This work discusses the difficult task of developing instructional settings and materials to guide students in achieving the complex competencies addressed.

Common Features of Post-Positivist Research

Common research topics. The primary concern of positivist/post-positivist research is to provide a rational explanation for a variety of educational phenomena, but it is often linked with a scientific test for effectiveness or efficiency of a teaching program or educational system—in other words, investigating what works and why it works for evidence-based educational practice (Feuer, Towne, & Shavelson, 2002). Studies that typically are within a post-positivist paradigm include intervention studies as seen in Ryoo and Linn's (2012) study and other educational software studies such as the one by van Borkulo, van Joolingen, Savelsbergh, and de Jong (2012); large-scale assessment studies such as No Child Left Behind (NCLB) in the United States (Dee & Jacob, 2011) and the National Assessment Program—Literacy and Numeracy (NAPLAN) in Australia (Dulfer, Polesel, & Rice, 2012); and international comparison studies such as the Trends in International Mathematics and Science Study (TIMSS; Thomson, Hillman, & Wernert, 2012) and the Programme for International Student Assessment (PISA; Organisation for Economic Cooperation and Development, 2010).

Common research designs. Based on logical empiricism, post-positivists painstakingly focus on establishing formal research designs and data that can self-evidently explain what is happening within education programs/systems and why. In order to make their knowledge claim more scientific and generalizable to other educational systems, post-positivists may adopt various research designs but frequently choose experiments (Ryoo & Linn, 2012) or large-scale surveys (Velayutham et al., 2011). For such research designs, researchers adopt comprehensive sampling strategies (e.g., stratified, systematic, or cluster sampling) to represent the target population, and they endeavor to control the variables (e.g., dependent, independent, or confounding variables) in various ways to establish a clear causal relationship (Porter, 1997). They also spend a significant amount of time methodically developing a quantitative instrument or rubric to record the research participants' understanding, perceptions, or behaviors (Jaeger, 1997). The general standards of quantitative study, such as reliability, internal and external validity, and statistical precision, are faithfully attended to (Cohen, Manion, & Morrison, 2011). While qualitative data may be collected for such research designs through interviews, observations, or students' essays, the data are converted into numbers to correspond to preset categories (Ryoo & Linn, 2012) or used to support or elaborate on the quantitative data as a form of triangulation (Velayutham et al., 2011).

Role of the researcher in relation to the participants. Like natural scientists, post-positivist education researchers aim to be unbiased, knowledgeable experts who contemplate an educational phenomenon at a distance (Schwandt, 2001). The researchers primarily rely on the previously established body of knowledge, their intellectual reasoning power, and their impartiality to the study to make knowledge claims (Moss et al., 2009). Their personal values/beliefs or their involvement with the research participants may damage the objectivity of the study, and post-positivist researchers strive not to become too involved with the participants to proceed with the study fairly. In Ryoo and Linn's (2012) study, the researchers were not directly involved in teaching the students themselves; rather, they were outsiders who sat in class to check the intervention protocols and collect the necessary data. They did not try to build any personal connection with the participating students. Similarly, for the studies of Velayutham and colleagues (2011) and of Holstenbach and colleagues (2011), the same basic relationship was established between the researchers and the participants, with no personal attachment with the participants.

Because of the limited connections with the participants, the ethical obligations of the post-positivist researchers to the researched are seemingly straightforward. They follow the ethical guidelines outlined by the Institutional Review Board or Ethics Committee (see, for example, the ethics approval process of the American Educational Research Association, 2011, and the Australian Association for Research in Education, 2005, or similar institutional departments). These guidelines involve voluntary participation, informing participants about the research procedures in advance, being sure to avoid physical and psychological harm to the participants, safeguarding the anonymity of the participants, and reporting the data honestly (Fraenkel et al., 2012).

Common quality standards. While many researchers characterize positivism/post-positivism in terms of rigorous research methods and verifiable data (Kincheloe & Tobin, 2009), D.C. Phillips (2005) argues that researchers in this tradition value not just the methods but also how the overall case is made. He explains that a research study should be firmly based on objective, comprehensive data, but the arguments of the study should also be meticulously structured to present the main argument convincingly. Robert Floden (Moss et al., 2009) focuses on the connection of the research study to the research community and to the established body of knowledge and lists three important criteria to judge the quality of research in this tradition: (a) clear definition of concepts/constructs that are employed in the study; (b) strong, logical reasoning throughout the research process—from literature review to interpretation of the empirical data to drawing of its conclusions; and (c) significant contribution of the study findings to educators or policy makers.

Common Report Styles: Most post-positivist researchers follow the traditional scientific research report format: starting from the literature review, research problem/questions, research design, data analysis, and discussion of research findings, and finishing with limitations and educational implications. The flow of the report is logically organized to demonstrate how scientifically the study was conducted. The procedures are elaborately described to enable replications. The report is frequently written in a passive voice or third-person narrative, such as "the data were collected" rather than "I collected the data," to give an impersonal, objective tone.

Interpretivist Research Paradigm

Philosophical Backgrounds of Interpretivist Research

Interpretivism emerged as the reaction against the prevalent "scientific" positivism research. Different from positivists and their search for the objective, generalizable truth of the world, interpretivists focus on the *localized meanings of human experience.* Stemming from the relativist ontology and constructivist epistemology, the researchers in this tradition focus on the fact that people construct their understanding based on their experiences, culture, and context. Even one simple action of shaking hands could be interpreted differently—as pleasant, too formal, or repulsive—depending on the social convention, location, time, and company. Likewise, when an educational program is introduced, a young, enthusiastic, personable Ms. Alison may interpret and implement it differently from an experienced, charismatic Mr. Buckley. Consequently, the "proven" effects of the educational program may have little relevance to the students in Ms. Alison's class because of the local educational context. Thus, interpretivist researchers are scornful of the positivists' effort to gloss over the specifics to generalize their research findings. They argue that measuring and generalizing human understanding and behaviors—as in positivist studies—do not tell the more important part of human action—the situated meanings that people make out of such social, educational interactions. Researchers in the interpretivist tradition thus do not overly claim generalizability of their findings into other situations, because people's meanings and intentions are contextual, temporal, and particular. While academic researchers often feel the urge to make generalizable knowledge claims—that could go beyond the immediate context of the study to be widely applicable to address the situation at hand—interpretivists aim to describe in detail people's lived experiences (Dewey, 1925/1981) regarding educational phenomena. If the audience of the study finds the researcher's interpretation plausible, informative, or thought provoking, the research is regarded as worthwhile (Wolcott, 2009).

Researching people's localized, subjective interpretation of social phenomena, however, involves multiple layers of complication. For example, how do we know researchers identified the true local meanings? Understanding people's lived experience is not the same as interviewing and transcribing every word into a research paper. Researchers need to interpret what the research participants have shared with them, and the participants would share only what they want to share with the researchers. Based on researchers' own personal, social, and cultural experiences, the information from the participants could be interpreted quite differently. In order for researchers to claim that they have a good understanding of the educational phenomenon or of the participants' lived experiences, they usually spend an extended period of time with the participants, build rapport, empathize with the participants to make better sense of the situation, and review their own interpretation with the participants and against the literature. While the interpretivist researchers strive to examine their own values and experiences to establish better understanding of the situation by conducting member checks, audit trails, and other means (Guba & Lincoln, 1989; Merriam, 2009), the researchers do not claim that their knowledge claim is a complete or the right one but that it is a sensible interpretation of the situation.

The subjectivity issue becomes more complicated when considering the audience of the research report. When interpretivist researchers describe their understanding of the educational phenomenon and of the research participants, the audience has to reinterpret the research findings. Based on the readers' lived experience, the meaning drawn from the research report would be different. Aware of the multiple levels of subjectivity—from the social interaction to the research participants, from the research participants to the researcher, and from the researcher to the audience—the researchers in this tradition often offer "thick descriptions" of the situation to communicate the researchers' interpretation (Geertz, 1973).

Examples of Interpretivist Research

Similar to researchers in anthropology, science education researchers in the interpretivist paradigm set out to examine in some detail the way that individuals—be they teachers, students, administrators, or parents—develop an understanding of their experiences and activities. Consequently, researchers spend much time studying participants and collecting large amounts of (mostly) qualitative data from observations, interviews, descriptive narratives, and the like. Interpretivist studies vary widely in the amount of structure, the length of time, and the level of engagement of the researchers with the participants. The following examples provide some evidence of the variety of interpretivist studies.

An example of a more methodical interpretivist research position is one by David Treagust, Roberta Jacobowitz, James J. Gallagher, and Joyce Parker (2001). The study explored how a middle school teacher used assessment embedded within her teaching the topic of sound. Jim Gallagher had studied ethnographic research methods under Fred Erickson and had been influential in disseminating interpretivist research methods in science education through national and international contacts. During an academic leave, Treagust joined Gallagher in conducting this case study and regularly went to the research site—a Grade 8 science class with 23 students—to explore how the teacher "incorporated assessment tasks as an integral part of her teaching about the topic of sound" (p. 140). Despite the fact that one of the co-authors (Jacobowitz) was the teacher of the class, the rest of the researchers made minimal interference of the classroom activities. After 3 weeks of intensive observations of science class and interviews with the teacher and the students, the researchers combed through the data to identify how the assessment strategies were used and contributed to or detracted from learning the sound concepts of the lessons. Consistent with the qualitative research design espoused by Erickson (1986, 2012), analysis of the data enabled the development of five assertions that focused on the embedded assessment tasks. Each of the assertions was supported by detailed data from the classroom observations, as well as interviews and analysis of materials produced by the students during the lessons. The research showed

> that nearly every activity had an assessment component integrated into it, that students had a wide range of opportunities to express their knowledge and understanding through writing tasks and oral questioning, and that individual students responded to and benefited from the different assessment techniques in various ways.
>
> (p. 137)

Taking a more philosophical perspective, Beth Warren, Cynthia Ballenger, Mark Ogonowski, Ann Rosebery, and Josiane Hudicourt-Barnes (2001) at the Cheche Konnen Center illustrated how Haitian immigrant elementary school children develop scientific discourse in relation to their everyday interactions. The science education researchers in the sociocultural tradition often regard science as a discourse of a scientific community and science learning as crossing borders or gaining control of multiple discourses (C.W. Anderson, 2007). Warren and her colleagues, however, argued that children's everyday discourse and a scientific one are not dichotomous but are in a continuum. Using detailed descriptions of students' and scientists' interactions, the researchers in this study support their points. One of the episodes in the study was about Jean-Charles. He was a Haitian immigrant student who spoke Haitian Creole (known not to contain technical, scientific, abstract terms) as his first language. The researchers had known the student and the class for a considerably long time, and they were able to describe the usual modes of Jean-Charles's interactions with his peers, how it took a long time for him to speak about his ideas, how his drawings were admired by others, and so forth. In analyzing a class dialogue on metamorphosis, the researchers dissected the meaning of each student's sentences—both literal and contextual meanings in which they were understood by the members of the class—and how the casual language use and the class environment contributed to the sense making of the metamorphosis of insects in relation to the human growth. In analyzing an interview with Jean-Charles, the researchers discovered how the use of his everyday language helped the young child to distinguish growth and transformation in a unique way. Questioning the value of dichotomy between everyday language and scientific language, the researchers concluded that educators need to observe more deeply and carefully how the students' negotiation of meanings could help their scientific sense making.

Heidi B. Carlone (2004) conducted an ethnographic case study, entering the field with a research question: How do students, especially girls, make sense of science and being a good science participant in a reform-based physics class? The focus is on the female students' experiences—the meanings they build from the instruction and the local culture within which they operate. Science learning is understood not as a cognitive activity but as a sociocultural activity that integrates students' identities, discourses, and values. Different from post-positivist researchers, Carlone actively sought to get to know the students and spent much time in their naturalistic setting—the physics classroom. Six weeks may not be regarded as a long enough time to call this study an ethnography, but she stayed at school as a participant observer and collected an extensive data set utilizing ethnographic practices—as did Treagust and colleagues (2001). She took field notes in class, talked with students informally and in interviews, collected students' documents, and interviewed the teacher and school administrators. Any verbal or behavioral data were entered into the data set. She might have had an initial research design, but as she was accumulating data, she redirected the research to follow up on the preliminary results of data analysis. Instead of summarizing students' responses to the interview questions, Carlone endeavored to portray the participants' experiences, values, and ways of thinking through their own words and actions. She allocated an extensive portion of the paper to demonstrate the subtle way the participants' experiences are integrated into their way of communicating by directly quoting them. Because of the thick description of the situation, readers feel as if they are sitting in the classroom or seeing through the participants' minds. In conclusion, rather than giving a definite answer to the research question, Carlone shows the complexities in implementing an inclusive science curriculum for diverse students and calls for more nuanced understanding of students' participation in science learning.

Interpretivist studies in German physics classrooms by Reinders Duit and his colleagues involved an examination of nonlinear systems, which play a significant role in contemporary science but are seldom discussed in school science. A research and development program investigated the educational significance of this new topic, and explorative studies were carried out to find out which ideas of nonlinear systems may be taught to Grade 10 students. In one of the major studies, 25 students worked in small groups and tried to investigate key features of simple chaotic systems. The work in three groups was video-documented. Using a methodological approach fusing conceptual change and a discourse perspective allowed descriptions and analyses of students' learning trajectories both in terms of conceptual change and in terms of minute shifts of students' language games (Duit, Roth, Komorek, & Wilbers, 1998). The studies were carried out within the framework of a theoretical model for instructional planning, the Model of Educational Reconstruction (Duit, Gropengießer, Kattmann, Komorek, & Parchmann, 2012). This model shares major features of design-based research (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). In the first steps of investigating whether a topic so far not included in the curriculum should be taught and may be taught in ordinary classroom settings, the results show how interpretive research designs are powerful. In this instructional program, the analytical and empirical (interpretive) research concerning the educational significance of the topic in question (understanding nonlinear systems) and the empirical (qualitative) research on the means to teach the new topic in schools resulted in a preliminary teaching and learning sequence. In addition, insights into the fine structure of analogy use were gained that in subsequent interpretive studies resulted in a model of analogy use. Briefly summarized, the studies resulted in preliminary ideas on teaching key issues of nonlinear systems and provided new insights in the fine structure of analogy use, partly challenging the predominating cognitive science approaches (Duit, Roth, Komorek, & Wilbers, 2001). Finally, another related exploratory study resulted in a "heuristic" model of analogy use (Wilbers & Duit, 2005), explaining why analogies provided by teachers often fail to achieve their intended aim.

Common Features of Interpretivist Research

Common research topics. Interpretivist studies focus on the cultures (Carlone, 2004), language use (Warren, Ballenger, Ogonowski, Rosebery, & Hudicourt-Barnes, 2001), classroom interactions (Gallas, 1995; Paley, 1981; Treagust et al., 2001), and lived experiences of students, teachers, scientists, and community members (Wong, 2002). Through the researcher's empathic identification with the participants and through reflection on the beliefs and values of the researcher and the society, researchers aim to understand the research participants' meaning making around science teaching and learning. Even when a new educational intervention program is implemented, the researchers in this tradition highlight the dynamic interactions between the program and the local contexts, and consider how the local participants interact with and understand the new program (Erickson & Gutierrez, 2002). The interpretivists do not expect that their research results could be readily or directly translated into general science education policies or strategies (Bryman, 2012).

Common research designs. As an interpretivist research study is perceived as a sense-making process for the researchers involved, the research design itself can evolve as illustrated by the studies by Duit and colleagues (2001), which is consistent with grounded theory. As the researchers immerse themselves in the situation, they get to know the "prominent" research questions better, develop a clearer focus, and may change the research design accordingly. The evolving research design is not something that is frowned upon, as in post-positivist research, but a natural process of interpretivist research. Interpretivist researchers tend to adopt qualitative research designs, such as case study, ethnography, narrative, and phenomenological research. The qualitative data collection methods tend to be interviews, observations, and document analysis. To capture the everyday experiences of the research participants, studies usually occur in naturalistic settings rather than experimental comparative settings as in post-positivist studies.

Role of the researcher in relation to the participants. Within the interpretivist paradigm, researchers do not aim to claim objectivity attained by disinterested, unbiased researchers. Because interpretivists believe that meanings are not pregiven but are co-created through hermeneutic dialogues (Schwandt, 2000), researchers often aim to study by engaging with the activities of the research participants (Clandinin & Rosiek, 2007; Guba & Lincoln, 2005; Wolcott, 2009). As the sense maker and narrator of the situation under study, the researcher may solicit the views of the research participants and sometimes seeks immersion in the situation to experience it him/herself. Because of the close relationship with the participants, researchers are obligated to consider many ethical issues beyond the Institutional Review Board guidelines, such as how to draw a boundary between the stories that are intriguing to readers and the stories that are too personal to pry into or too consequential to report, or how much to honor the participants' willingness to share their stories when they do not fully grasp the meaning of participating in a research project (Clark & Sharf, 2007; Einarsdottir, 2007; Etherington, 2007; Jones & Stanley, 2008).

Common quality standards. Interpretivist researchers admit that the quality of research depends on the skills, sensitivity, and integrity of the researcher because research itself is a sense-making process. Frederick Erickson (Moss et al., 2009) categorizes the criteria to judge quality interpretivist research study into two areas: the technical aspects and the educational imagination. Technical aspects involve: (a) prolonged, meaningful interaction in the field; (b) careful, repeated sifting through the data; (c) reflective analysis of the data; and (d) clear, rich reporting. However, interpretivists focus more on the substance than on the methodical rigor by itself, and that is what Erickson meant by educational imagination. One of the criteria most interpretivist researchers uphold is crystallization (Denzin & Lincoln, 2011). Like a clear crystal that casts multiple colors, the researchers endeavor to create a strong image of the lived experiences of the participants through comprehensive deliberation and persuasive presentation (p. 5). As a general guideline for interpretivist research studies, Tracy (2010) offers eight criteria: a worthy, relevant, significant topic; rich data and appropriate theoretical construct; researcher's reflexivity and transparency in value and biases; credible data through thick description and respondents' validation; aesthetic representation of findings; significant contribution in theory and practice; ethical; and meaningful coherence of study. Interestingly enough, a few of these criteria sound very similar to the post-positivist quality standards listed earlier.

Common report styles. The most distinctive feature of interpretivist studies is that the data are qualitative, much of which is thick description of the situation (individuals, contexts, or events). Lengthy transcripts or rich, verbal descriptions of a situation often characterize interpretivist research. The report could take the form of a traditional empirical study with literature review, methods description, and data analysis (Carlone, 2004). Or it could take a narrative format of describing a daily procedure of a schoolteacher or children's discussion in class (Gallas, 1995, 1997; Paley, 1981). In such narrative reports, researchers do not make a long validity claim or methodological justification; they simply describe what they have done and explain why. Yet the writing is not an easy task for interpretivist researchers. It is "endlessly creative and interpretive" (Denzin & Lincoln, 2011, p. 14). Researchers often ask questions such as: How much contextual description is enough for the readers? How much analysis and how much description are adequate? Through whose voice is the story told? (Wolcott, 2009). The rich description of research participants' lived experience needs to be artfully woven into researchers' interpretations, and the researchers' writing ability (or storytelling ability) is counted critical. Interpretivist researchers do not regard their interpretation of the situation as the absolute truth, so they tend not to provide the final words (or conclusions) of the study (Wolcott, 2009).

However, in science education research journals, the extent of this thick description is often limited by the page requirements of the journal, and only short episodes can be reported. Depending on who reviews such work, these abbreviated thick descriptions or dialogues can be seen as not meeting the necessary criteria. In addition, many research reports lack the detailed description of how the researchers selected the participants, why they chose to focus on certain aspects or data collection methods, what they did to ensure the quality of data analysis, and how they considered alternative interpretations. Yet, in recent years, sociocultural, interpretivist research studies appear more frequently in major science education journals such as *Journal of Research in Science Teaching* and *Science Education* (Carter, 2007; Hammond & Brandt, 2004). *Cultural Studies in Science Education* publishes articles with this particular focus and has greatly widened the scope of work that is designed to better understand science as a cultural practice. Research studies in this tradition aim to integrate students' cognition with the context (Hammond & Brandt, 2004).

Critical Theory[1] Research Paradigm

Philosophical Backgrounds of Critical Theory Research

Similar to interpretivist researchers, critical theory researchers acknowledge that people's values, ideas, and facts are shaped by social, political, cultural, economic, gender, and ethnic experiences. Critical theory researchers, however, put more focus on *the inequality and the power dynamics* in human interactions because they understand that all ideas and social interactions are "fundamentally mediated by power relations" (Kincheloe & McLaren, 2005, p. 304). This tradition could be traced back to Marxism in terms of the exploration of unequal power relationships and power struggles. They view that "social reality is not always what it should or could be," but the social arrangements make people feel comfortable with the status quo (Kincheloe & McLaren, 2005). Academia contributes to such social arrangements by making people develop false consciousness to believe the existing body of knowledge is neutral and scientific (rather than a tool to serve a certain group of people), effectively preventing people from questioning the status quo (Kincheloe & Tobin, 2009). Clandinin and Rosiek (2007) observe that the critical theory researchers believe that "large scale social arrangements conspire not only to physically disempower individuals and groups but also to epistemically disempower people" (p. 47).

Because the social narrative is conceptualized that way, researchers strive to examine the current social values and roles in historical and cultural contexts and problematize many taken-for-granted ideas for the benefit of socially marginalized people, such as: Is science learning or educational reform really beneficial for everyone (Barton & Osborne, 2001; Eisenhart, Finkel, & Marion, 1996)? Why don't ethnic minority students or female students participate in school science as much as their white male counterparts (Lee, 2002; Noddings, 1998)? Isn't there something that inherently discourages them from learning science at school (Aikenhead & Jegede, 1999; Allen & Crawley, 1998; Brickhouse, Lowery, & Schultz, 2000; Harding, 1991)?

By asking such philosophical questions, researchers in this tradition focus on uncovering the unequal power relationship in societies and institutions. They aim not just to expand the knowledge of the society but to contribute to transform the society and emancipate the disempowered people (Kincheloe, 2003). Carter (2007) argued, "science education should not only work toward a deeper understanding of our planetary systems but also toward the explicit goals of creating a more just, equitable, and sustainable world" (p. 175). Researchers ask themselves, "If the society or science education is not open, democratic and equal, what should we do to change, as teacher, educational researcher, and concerned community member?" (Bouillion & Gomez, 2001; Elmesky & Tobin, 2005; Fusco, 2001; Roth & Desautels, 2002; Tan & Barton, 2008). In order to enact changes in the lives of the socially, economically, and historically marginalized people, they often go into the low-income, ethnic-minority-neighborhood schools and become involved in some type of an action project.

Examples of Critical Theory Research

Critical theory research studies may look quite different from more "traditional" research studies in terms of their

(1) critique of the social discourse/structure; (2) orientation toward social action and change; (3) explicit analysis on the researchers' identities, values, and intentions; and (4) experimental way of writing research reports (Kincheloe, 2003). The first two studies discussed (by Bouillion & Gomez and by Elmesky & Tobin) illustrate how science education researchers attempted to change how schooling or social research is done. They first pointed out the limitations of the status quo and then enacted alternative ways. Their primary goal was not only to observe but also to change the situation and empower the students and their community for the betterment of the people involved. The third study (by Tan & Barton) was conducted in the same vein as the first two, but this study may look very similar to an interpretivist study in terms of the authors' defense of research methods, presentation of results, and interpretations. The last study (by Eisenhart) is a critical autoethnographic study in which the author conveys her own experience and reflections as "data." The author made clear that her critical interpretation of the social phenomena was socially and politically motivated. These studies follow different research methods and reporting styles. Despite the difference, we put them in this critical research tradition because of their explicit focus on challenging the inequality of the status quo and the commitment toward social change (Maulucci, 2012).

Lisa Bouillion and Louis Gomez (2001) conducted an action-oriented, transformative research study at an elementary school in a low-income urban neighborhood in Chicago, Illinois. Instead of following the traditional school learning model, the researchers along with the teachers at the school implemented a science project in which science was taught beyond the school walls and promoted the school–community partnership. The project was called the Chicago River Project. As students recognized illegally dumped garbage was a major community problem, they investigated the environmental issues scientifically in terms of river pollution and water safety. They shared the results with other community members through writing. They organized a series of actions to change the situation. The project was not just one of interesting school activities for the teachers and students. It was their own community problem that they found intimately relevant and in need of action. As the project evolved, the researchers not only collected data for the research report, they also helped the students and teachers make the action project successful. The researchers aimed to change the existing practice of science teaching at the school and to break down several existing power relations or boundaries through the study: between students and science as they become users and producers of scientific knowledge with the help from local community activist-scientists; between teachers and students as students' ideas were purposefully incorporated into the activity planning and execution; between education researchers and schoolteachers as they became equal contributors in the collaborative project; and between students and the city council as the students' persistent effort persuaded the city to act on behalf of the community. While the research report may look similar to a qualitative study, a major goal of this study was to effect a change in the community and the identity of students and teachers within their learning environments.

In conventional educational research, students are often the ones who supply data for the research project by filling out questionnaires, answering competency tests, or responding to interview questions, while researchers design, execute, and analyze the study. Rowhea Elmesky and Kenneth Tobin (2005) conducted a study trying to change the power imbalance in the research process. Instead of following the conventional model of objectifying students' ideas, Elmesky and Tobin involved students as the collaborative researchers rather than as subjects. Elmesky and Tobin framed their research study as an alternative to the status quo educational research in American inner-city (low-income, ethnic-minority neighborhood) schools. They started their study by questioning the effectiveness or the true intention of educational programs in improving the scientific literacy of students in socially marginalized communities. Because they saw that the cultural deficit view on the marginalized is oppressive and hegemonic, the researchers adopted a research method that would value the students' cultural resources and empower them. Following the model of Joe Kincheloe and Shirley Steinberg (1998), the researchers recruited high school students as collaborative researchers so as to equip them with critical research skills and to challenge the conventional role of students as the researched. The students were not only provided with multiple research opportunities to reflect on their own ideas and their school life, but they also worked as a resource to shed a new light on the ways to appreciate their culture and educate how to teach in low-income-neighborhood schools. When presenting their research project, the researchers used a transcript format (as if they were research participants) for their interpretation of students and sometimes they used a research narrative format (as if they were the authoritative researchers). The mixed formats of presenting their interpretations gave the impression that they were just telling their version of the stories, not the authoritative interpretation.

Edna Tan and Angela Barton (2008) started their study in a similar tone to Elmesky and Tobin's by critiquing the implementation of the American national initiative for scientific literacy. Tan and Barton argued that the current education initiatives focus on the test scores and marginalize low-income, ethnic-minority students by framing them as "problem" or "failure" and by depriving them of learning opportunities to make meaningful personal connections to science. After a discussion of a feminist stance on the global knowledge economy, the researchers carefully described how two sixth-grade ethnic-minority girls from a low-income-neighborhood school negotiated their identities through various school science activities and their interactions with the teacher and peers. While the researchers adopted the format of an ethnographic case study in analyzing and presenting the students' interactions, they did so to problematize the status quo in school science and education research.

Within the frame of critical autoethnographic, reflective research, Margaret Eisenhart (2000) told her own story of publishing a book on women's participation in various venues of science. At the beginning of the paper, she explicitly mentioned that her story is not value neutral—rather, it is positioned with certain values and purpose. She intended to critically reflect on how she, as an established academic, conceptualizes and practices science education research, and how the larger sociocultural discourse shapes or constrains her practice. Retelling her story in two parts, she straightforwardly described why she wanted to investigate various science-related activities in which women were successfully participating and how she designed a multiple-case study, including a case of the pro-choice and pro-life activist groups' use of science. She portrayed that the participants in the pro-choice and pro-life groups were highly educated, politically charged, and strongly committed to learn and use science, but their use of science was "unsophisticated" and "divisive" (p. 48). In the second part of her story, she described a series of encounters with strong discouragement to include the story of the pro-choice and pro-life groups in the book. Publishers and reviewers adamantly noted that those groups' stories did not add anything new or valuable to the book. Initially, she blamed her inability to write persuasive, convincing arguments and tried to revise the writing. However, from the fear of not being able to publish the book, she conformed to the expectation of the publisher and the society. Eisenhart later reflected on the reason people isolated the pro-choice and pro-life groups' stories, how the invisible boundary of what's counted as scientific activities played a role in their omission, and what she could have done differently. In the paper, Eisenhart continuously reminded the reader what she was doing and why—for example, why she constructed her story in a more academically conventional way and how placing the blame for what happened to the larger social discourse eased her guilty conscience when relating to her co-author. This reflective, honest piece of writing leads us to reconsider the social meaning of what we do in the research process in a new light.

Common Features of Critical Theory Research

Common research topics. While a large portion of science education studies focuses on the technical aspects of how to teach science better, critical theory researchers concentrate on the political and historical aspects of education and educational inequality, seeking to challenge the status quo. The obvious topic for the critical researchers is investigating multiple, subtle ways to discourage or marginalize the participation of socially disadvantaged people in schooling or science. For example, Sandra Harding (1991) questioned how science and science education are framed in our society and how they have systematically discouraged women's participation and contribution. Allen and Crawley (1998) investigated how school science excludes the worldview of Native American students and the elders and how it prevents their successful learning. Barton and her colleagues (Barton, 1998; Barton & Osborne, 1998; Barton & Yang, 2000) investigated how families in a homeless shelter were dissuaded from succeeding in school science.

Common research designs. The designs of critical theory research are often very similar to those of interpretivist studies, but with more explicit emphasis on larger social ideologies and power relationships. Critical theory researchers believe that empirical research and its data, no matter how rigorous the research methods are, cannot escape the dominant narrative of the society (Kincheloe, 2003). Because of this limitation, researchers in this tradition try to be critical of researchers' own assumptions and their relationship with the researched. Interpretivist researchers often display reflexivity in their relation with the research participants in terms of their values and experiences in understanding the participants. Critical theory researchers, on the other hand, show their reflexivity in terms of power dynamics between the researchers and the researched and even what the research participants have shared as their experiences. In critical ethnography, "[researchers] will be listening through the person's story to hear the operation of broader social discourses shaping that person's story of their experience" (Clandinin & Rosiek, 2007, p. 55). Listening to people's stories is a way to uncover the larger social discourse and false consciousness to enlighten the public.

Another common research design is participatory action research that actively addresses the inequalities in school and community. Researchers go into a low-income neighborhood and involve students and community members to recognize the issue of the community and take actions to change situations and their identities. Studies by Bouillion and Gomez (2001) and by Elmesky and Tobin (2005) could be examples.

Role of the researcher. The main goal of research is not expanding the body of knowledge but challenging and transforming the society and institution for the betterment of the people involved. Rather than distant, unbiased scholars, the critical theory researchers claim they are enlightened intellectuals and activists, working for social justice and for the people who are socially and politically disempowered (Fine, Weis, Weseen, & Wong, 2000).

Common quality standards. Because critical theory researchers are skeptical of unbiased research through rigorous methodical measures, they do not provide a set of guidelines on how to ascertain quality research. Rather, they argue that by explicitly discussing the biases of researchers and societies, they are conducting more "objective" research studies because they are not operating under any "hidden agenda" or exacerbating social inequality. However, they highly value the democratic procedures in research (e.g., egalitarian relationship with research participants, democratic decision making, and shared contributions to study) and the social impact of the study in transforming society (e.g., greater understanding of the society, the empowerment of the participants, and prompting or enacting changes in social/personal practices) (G. Anderson, Herr, & Nihlen, 1994; Greenwood & Levin, 1998; Griffiths, 1998).

Common report styles. Because they are consciously problematizing what is given or conventional, critical theory researchers intentionally do not follow the traditional fabric of research report. They experiment with the reporting of the study, such as adopting a performance or writing the story as a fiction (Flores-González, Rodriguez, & Rodriguez-Muniz, 2006). Some social-action-oriented research studies could be regarded as less methodically rigorous, thus not meeting the criteria of many academic journals. Consequently, to address this potential concern, many critical theory researchers adopt less radical, more traditional forms of ethnographic research reports, such as those by Barton (1998) and by Eisenhart (2000).

Paradigmatic or Pragmatic Research in Science Education

Science education researchers, like any other social science researchers, strive to establish the credibility and validity of their studies. Locating their studies within a particular research tradition or paradigm gives researchers philosophical, methodological, and practical guidelines to design and conduct a persuasive and convincing research project. In the preceding pages, we have described three research traditions and identified relevant studies that illustrate post-positivist, interpretivist, and critical theory paradigms in terms of the underlying epistemological, ontological, and methodological differences. We aimed to show how a research paradigm frames research effort by conditioning the research topics to be studied, the research designs used, the role of the researcher in relation to the participants, the common quality standards, and the common report styles presented. As we noted in the introduction to this chapter, we do not distinguish between different paradigms on the basis of whether the data are qualitative or quantitative, even though there is a tendency for post-positivist researchers to use mainly quantitative data and for interpretivist and critical theory researchers to use qualitative data extensively.

However, some science education researchers might wonder why we have not included mixed-methods approach as a research paradigm. Many contemporary research studies have both quantitative and qualitative data, and they may not seem to fit nicely into any specific research paradigm. Mixed-methods researchers (e.g., Creswell, 2012; Morgan, 2007) are not committed to any particular perspective on the nature of knowledge or reality, and they believe that dichotomizing quantitative and qualitative is not only unproductive but fallacious (Ercikan & Roth, 2006). They even question the practical value of research paradigms. David Morgan (2007), for example, claims that when designing and executing research projects, researchers tend to focus on practical aspects of research design and methods rather than worldviews or paradigms. Evaluative educational researchers, on the other hand, focus on diverse stakeholders' demands (Greene, 2008). No matter the worldview of the researchers, they are obligated to adopt various research approaches to satisfy the demands of diverse stakeholders (e.g., large-scale statistical analysis for policy makers or contextual vignettes for parents of students' welfare programs). Other mixed-methods researchers claim that the mixed use of quantitative and qualitative data enables a thorough triangulation of the findings and makes stronger knowledge claims (Creswell, 2012; Mathison, 1988; Reeves, 1997). Philosophically, though, Bryman (2012) regards this mixed-methods approach as qualitative researchers' practical attempts to establish themselves in a post-positivist-dominated academic world without committing themselves too much to the interpretivists' research paradigm. Others (e.g., Greene, 2008) focus on the practical problem-solving approach and the dynamic interplay of theory and practice in this tradition and list John Dewey's (1938/1991) pragmatism as their philosophical framework.

Given the circumstances, the authors of this chapter had a dilemma: whether to regard mixed methods as a separate research paradigm or as a research design. As Bryman (2008) notes, combining different research methods is an area in which researchers still have different views. While many post-positivist researchers welcome such adjustment as a way to increase the validity of research findings, interpretivist researchers are rather critical of such approaches. Denzin and Lincoln (2011), for example, regard it as a remnant of positivist legacies that relies on numbers as scientific evidence, resisting acknowledging the value of interpretivist qualitative studies and the political issue of what counts as evidence. Next, we list a few studies that adopt mixed-methods approaches to help readers recognize the similarities and differences between paradigmatic research studies and mixed-methods research studies.

Using an overtly described two-phase, sequential mixed-methods study, Sedat Ucar, Kathy Cabe Trundle, and Lawrence Krissek (2011) examined the effects of an intervention with preservice teachers at various educational levels in terms of their conceptual understanding. Following inquiry-based instruction using archived, online data about tides, a total of 79 preservice teachers completed a questionnaire, and subsequently a subset of 29 participants was interviewed. From the qualitative and quantitative data, the authors described and measured the impact of the intervention. The manner in which the quantitative and qualitative data were analyzed was described in detail, including reliability and trustworthiness measures. The findings were presented as a response to the research questions and discussed in relation to previous literature, with implications made for teacher education and future research.

As an example of another clearly described mixed-methods study, Liesl Hohenshell and Brian Hand (2006) investigated whether differences in student performance on science tests was a direct result of the implementation of a science writing program when the students in Grades 9 and 10 were learning cell biology. In this "mixed-method, quasi-experimental [study] . . . with a non-random sample" (p. 267), the researchers investigated the students' performance and explored students' perceptions of the writing activities using a survey and semistructured interviews. The authors emphasized the complementary role of quantitative and qualitative methods by using the quantitative results to document science achievement while using the qualitative data to enhance their interpretation of any findings arising from the quantitative data. The data interpretation was presented separately for the quantitative and qualitative analyses, as were the initial results. In drawing five assertions arising from the study, the authors integrated the analysis of the quantitative and qualitative data.

In a similar manner, Renee Clary and James Wandersee (2007) used a concurrent mixed-methods research design to investigate whether an integrated study of petrified wood could help students gain an improved geobiological understanding of fossilization, geologic time, and evolution. The researchers adopted Creswell's QUAL and QUAN approaches "to cross validate, confirm or corroborate the findings" (p. 1016). A survey about petrified wood was used pre- and postinstruction in a quasi-experimental setting, with the treatment class receiving the integrated petrified wood instruction. In addition to the quantitative data from the survey, qualitative data were collected from the content analysis of students' free responses on the survey as well as from the discussion board feedback and researchers' field notes. Some of the qualitative data were later quantified. Although there were quantitative and qualitative data from this investigation, the qualitative data were used to support the findings from the quantitative data. The students who experienced the integrated petrified wood instruction showed greater knowledge about aspects of petrified wood and geologic time; geochemistry of fossilization remained problematic for both groups.

Vaughan Prain and Bruce Waldrip (2006) conducted research with a group of teachers and their Year 4 through 6 students when they engaged with multiple representations of the same science concepts in electrical circuits and collisions and vehicle safety. Using "a mixed-methods approach entailing collection and analysis of both quantitative and qualitative data within the same study, including triangulation of different data sources" (p. 1848), the authors identified teachers' and students' practices and beliefs in using multimodal representations of science concepts. Based on survey responses from 20 teachers and their students, 6 teachers and their classes were selected for a case study of their classroom practice with a multimodal focus. The data included classroom observations and interviews with students when they were involved in classroom activities. Two science classes were observed. While these two teachers used various modes to engage students, the researchers observed that the teachers were not systematic in developing students' knowledge integration and their effective use of different modes. Students who demonstrated conceptual understanding were those who recognized the relationships between modes.

So what are the differences and what are the commonalities between these examples of overtly mixed-methods studies compared to those studies we have described based on a specific paradigm? From this review, what becomes evident to us is that mixed methods often involve an intervention and its evaluation, and mixed-methods researchers essentially work within an unstated post-positivist paradigm. They use quantitative and qualitative data in a complementary manner as far as possible. However, as we noted in the introduction of this chapter, we acknowledge that the development and use of mixed methods has, to a certain degree, moderated the antagonism between researchers working in different paradigms (Bryman, 2008). Jennifer Greene (2008) writes,

> A mixed-methods way of thinking is an orientation toward social inquiry that actively invites us to participate in dialogue about multiple ways of seeing and hearing, multiple ways of making sense of the social world, and multiple standpoints on what is important and to be valued and cherished.
>
> (p. 20)

Greene believes that "the mixed-methods approach to social inquiry has the potential to be a distinctive methodology within the honoured traditions of social science. . . because it embraces multiple paradigm traditions" (p. 20). If readers are interested in further discussions about the character and value of research paradigms and mixed-methods research, please further refer to Greene's paper.

In this chapter, we have reviewed how three well-known research paradigms are presented or practiced in science education research in recent years. The landscape of conducting research within these paradigms has gradually changed over the years, and in the concluding section, we have indicated how once-incommensurable paradigmatic positions have been embraced in mixed-methods research approaches. In the years ahead, we can imagine that approaches to research will continuously evolve to incorporate new issues and ideas. We hope our review can contribute to productive discussion of science education researchers across different paradigms, including pragmatic research with mixed methods.

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Note

1. Critical theory studies include several research traditions, such as feminism, postcolonialism, poststructuralism, emancipatory/participatory, postmodernism, etc.

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The Central Role of Assessment in Pedagogy

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