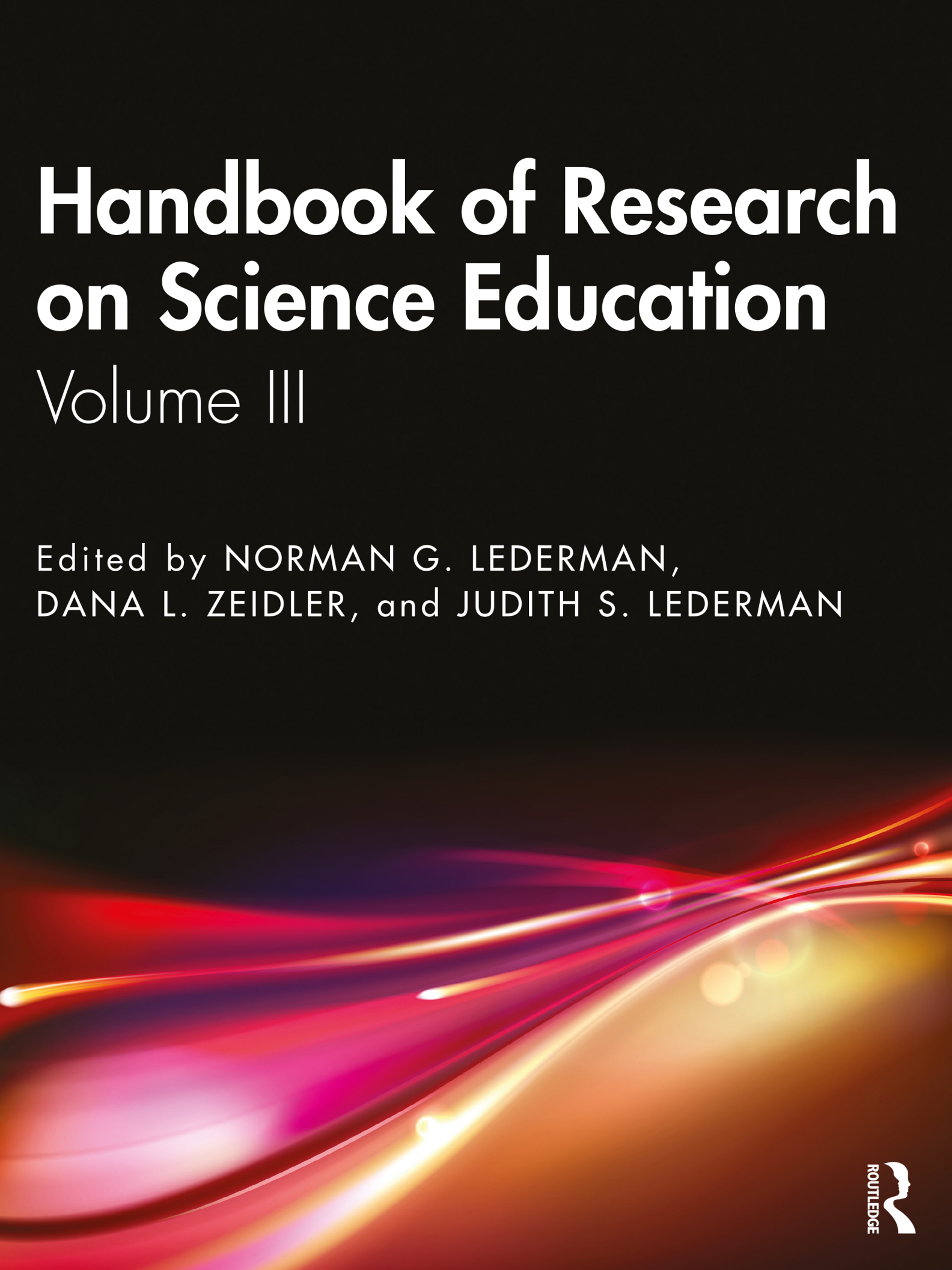
Handbook of Research on Science Education

Volume III

Edited by NORMAN G. LEDERMAN,
DANA L. ZEIDLER, and JUDITH S. LEDERMAN



ROUTLEDGE

HANDBOOK OF RESEARCH ON SCIENCE EDUCATION

Volume III

Volume III of this landmark synthesis of research offers a comprehensive, state-of-the-art survey highlighting new and emerging research perspectives in science education.

Building on the foundations set in Volumes I and II, Volume III provides a globally minded, up-to-the-minute survey of the science education research community and represents the diversity of the field. Each chapter has been updated with new research and new content, and Volume III has been further developed to include new and expanded coverage on astronomy and space education, epistemic practices related to socioscientific issues, design-based research, interdisciplinary and STEM education, inclusive science education, and the global impact of nature of science and scientific inquiry literacy.

As with the previous volumes, Volume III is organized around six themes: theory and methods of science education research; science learning; diversity and equity; science teaching; curriculum and assessment; 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 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, scholars, and graduate students, and pointing toward future directions of the field, *Handbook of Research on Science Education Research, Volume III* offers an essential resource to all members of the science education community.

Norman G. Lederman (deceased) was the Distinguished Professor and Chair, Department of Mathematics and Science Education, Illinois Institute of Technology, USA.

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HANDBOOK OF RESEARCH ON SCIENCE EDUCATION

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PREFACE

The third volume of this handbook builds on the seminal work of its predecessors. Volume I, published in 2007, was edited by Sandra K. Abel and Norman G. Lederman. This original volume provided the field with the first comprehensive synthesis of empirical and theoretical research represented by international scholars. The publication of Volume II, edited by Norman G. Lederman and Sandra K. Abell in 2014, carried this scholarship forward with attention to the coherent synthesis of newer research that informed theory, policy, and practice, as well as attention to emerging fields of research. Now, in 2023, we find ourselves building on the shoulders of our colleagues. In Volume III, edited by Norman G. Lederman, Dana L. Zeidler, and Judith S. Lederman, our aim is to build on past research, getting seminal works down to a science, and infuse it with the most insightful current research, raising it up to a state-of-the art collection of the most relevant themes and research to science education. We have confidence that the work in this volume will enrich our current understandings of theory, policy, and practice, as well as stimulate the growth of new directions of fruitful research that will inform our field and as it continues to evolve with the zeitgeist and tenor of the times.

This venture has not been without its unforeseen challenges on so many levels. The loss of a loving husband, colleague, and close friend made the development and production of this volume, to say the least, a difficult journey. We hereby dedicate this volume to Dr. Norman G. Lederman, who would have been quite disappointed in us had we not brought this work to its natural fruition! In a metaphorical, Aristotelian way, we can think of Norm as an unmoved mover – coalescing so many scholars around the globe to contribute their time and energy to something he deemed critical to the field. To partake in this venture, with the collective goal of promoting human flourishing through the exercise of virtues of character and the quest for scientific literacy, is Norm's legacy. Volume III is dedicated to you, Norm!

Of course, much of the development of this book took place as all of us confronted the ravishing global effects of COVID-19, and the many variants that followed. Many of the section editors and authors were faced with life-altering decisions about family, friends, professional colleagues, and rethinking how to effectively educate in the absence of the sociocultural contexts we had taken for granted. There may be topics that the reader would wish were included but could not be because of the personal hardships confronting all of us. However, it may count as a minor marvel that so many international scholars persevered to contribute to this volume, highlighting contemporary and emerging research perspectives. It may have taken a bit longer to bring this current project to conclusion than originally anticipated. We are grateful for the understanding and dedicated efforts

of all who contributed to this collective endeavor, and we are confident that Volume III represents a compendium of the best global research lines impacting science education research.

The research in this volume is presented in six sections representing major themes in current research. They are as follows:

Section I. *Theory and Methods of Science Education Research*
Section Editor: William Boone, Miami University

Section II. *Science Learning*
Section Editor: Richard A. Duschl, Southern Methodist University

Section III. *Diversity and Equity in Science Learning*
Section Editors: Cory A. Buxton, Oregon State University, and Okhee Lee, New York University

Section IV. *Science Teaching*
Section Editors: Jan van Driel, University of Melbourne, and Charlene Czerniak, University of Toledo

Section V. *Curriculum and Assessment in Science*
Section Editors: Bronwen Cowen, The University of Waikato, Hamilton, and Anders Jonsson, Kristianstad University

Section VI. *Science Teacher Education*
Section Editor: Saouma Boujaoude, American University of Beirut

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We want to acknowledge the work of our Managing Editors, who helped to right the ship if we meandered off course, worked closely with our publisher to make sure all the files were consistent with publication requirements, and applied their technical expertise to formatting and indexing the many manuscripts that comprise this volume. They are Dr. Dionysius Gnanakkan, Illinois Institute of Technology, and Constantine Shuniak, University of South Florida. We could not have completed this task without their dedicated efforts.

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SECTION I

Theory and Methods of Science Education Research

Section Editor: William Boone

1

PARADIGMS IN SCIENCE EDUCATION RESEARCH

David F. Treagust and Mihye Won

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: 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? (Guba & Lincoln, 1994). Like G. 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 to reporting the findings.

As Kuhn noted, although the paradigm is firmly based on the philosophical stance and has a significant influence over every aspect of the research procedures, researchers take for granted the paradigm in which they work, if they consider the paradigm at all. Indeed, researchers often have little or no knowledge of the historical grounding of the philosophical positions behind the paradigm, and consequently, they do not recognize the implications for conducting research. Indeed, in our recent informal review of research papers in science education when preparing for this chapter, the majority of authors do not refer explicitly to the paradigm that frames their research. In a similar manner, research methods books, particularly qualitative research methods books, discuss philosophical foundations and differences between quantitative and qualitative studies without necessary mentioning paradigms. Generally, the focus is 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 (e.g., Creswell & Guetterman, 2019; Fraenkel et al., 2019; Wiersma & Jurs, 2009). In such discussions of the research process, educational researchers view their studies mainly in terms of technicalities, without acknowledging worldviews that shape and validate their knowledge claims (Kincheloe & Tobin, 2009). In more recent editions, some comprehensive research methods texts do discuss research paradigms and philosophical backgrounds, but largely in terms of the procedural differences between quantitative and qualitative data collection (Cohen et al., 2011; Punch & Oancea, 2014). Despite their importance, in most research papers and educational research methods books, research paradigms are rather hidden from plain view.

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The fact that many people conduct studies without seriously considering research paradigms may be interpreted that the practical aspects of selecting a research paradigm are not as paramount as some researchers believe should be the case (Bryman, 2008). Some researchers even regard discussion of paradigms as a purely philosophical exercise, a remnant of the paradigm wars in the 1980s and 90s (Morgan, 2007). Reflecting on this time period, the 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 taking an interpretivist and/or critical stance. 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 acknowledgment of the contributions that research from different paradigms brings to the education community (Bredo, 2009).

In recent years, there have been 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 the United States by the National Research Council (NRC) (2002) and by other research-funding organizations dogmatically promote a certain type of research studies under the banner of evidence-based, scientific research, implying quantitative experimental design studies. At the time, this position by the NRC was not well considered by researchers in education who believed that it is dangerous to have such a limited view on what "other" types of research could contribute to establishing better education (see especially Feuer et al., 2002). (A detailed discussion of this issue is available in *Educational Researcher* in 2002 [volume 31, issue 8] and 2009 [volume 38, issues 6–7] and *Qualitative Inquiry* in 2004 [volume 10, issue 1].)

Furthermore, in the education community, and in the science education community in particular, there is still 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 methodologically 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 practice, this more balanced knowledge base is evident from an extensive review of 137,024 doctoral dissertations in education in US universities from 1980 to 2012, which showed an increased popularity of the interpretive research approaches during this period (Munoz-Najar Galvez et al., 2020). Further, there has been a willingness to move away from paradigm wars and examine the emergence of new approaches that address the complexities of educational research (Pivovarova et al., 2020).

We intentionally did not use the common category distinction of quantitative and qualitative research in this chapter because the category could be misleading – as if paradigm is limited to the choice of data-collection methods. As mentioned earlier, we believe a research paradigm is much more encompassing than the choice of data types. It is not helpful when a US government report – *Common guidelines for educational research and development* (Earle et al., 2013) – presents six types of research without any mention of paradigms. In our view, without an analytical understanding of each research paradigm, it is easy to misjudge the quality and the value of research to be investigated and miss the opportunities to learn from them (Moss et al., 2009).

In this chapter, we discuss four research paradigms – positivist/post-positivist, interpretivist/constructivist, critical theory, and mixed methods. While there are many different categorizations and

boundary drawings of research paradigms (Clandinin & Rosiek, 2007; Lincoln & Guba, 2000; Moss et al., 2009; Taylor et al., 2012), we chose those four to illustrate their own philosophical underpinnings or theoretical frameworks that guide research procedures and discuss how each paradigm is realized in various research studies in science education. Positivist/post-positivist researchers, based on realist worldviews, attempt to discover the truth by emulating "scientific" research with solid literature backgrounds and "objective" and rigorous research methods. Interpretivist researchers, based on relativist or constructivist worldviews, endeavor to make sense of the social phenomena through a lens of participants, demanding researchers of flexibility, open-mindedness, and reflexivity in design and execution of the research. Critical theory researchers, based on feminist, post-modernist, and other critical worldviews, challenge the status quo by questioning common assumptions and practices to create a more equitable, democratic society. In addition to research being conducted and framed within these three paradigms (even when not overtly mentioned), over the past three decades, a strong argument has emerged for what is referred to as the fourth pragmatic paradigm (Lukenchuk & Kolich, 2013). In this paradigm, mixed-methods researchers in education are not constrained by the underlying philosophies of the three paradigms referred to earlier and choose to not consider the philosophical underpinning of research, focusing on answering specific research questions.

By describing selected research articles that reflect the different paradigms referenced in the science education research field, we reflect on our own research practices and facilitate a dialogue across paradigms among science education researchers.

Post-Positivist Research Paradigm

Philosophical Backgrounds and Theoretical Frameworks of Post-Positivist Research Studies

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 the 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, but modified forms of positivism are quite prevalent and influential in the education field.

Different from positivists, post-positivists do admit that culture, personal value systems, and other surroundings influence an individual's 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 or not. 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 approach

the truth (or warranted assertions to borrow from John Dewey [1938/1991]) and are able to inform the people of interest (teachers, policymakers, parents, students, etc.) in order to help make data-driven decisions, for example, on a new educational program or educational improvement plans (in this case, informing teachers which teaching method is better for improving student achievement).

Examples of Post-Positivist Research Studies

Similar to research in the natural sciences or psychology, the post-positivist tradition focuses on seeking a scientifically rational or 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 five research studies from the science education literature with which we are familiar to illustrate the common features. These studies are not the result of an exhaustive review of the 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 post-tests. 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 (five years); within each teacher's class, the students were randomly assigned into two groups after a pre-test; 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 have 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, Sunitadevi Velayutham et al. (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 very important to obtain 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 interview. 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. These competencies include understanding and application of science concepts, principles and views of the nature of science and evaluation, and judgment about the role of science knowledge in understanding key problems of society and the life world. Julia Holstenbach et al. (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 included 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 to develop instructional settings and materials to guide students in achieving the complex competencies addressed.

Secondary analyses where the research is presented as objective, logical, and evidence-based, with the researchers having no contact with the participants or the research sites, also fit within the post-positivist design. Hsin-Hui Wang et al. (2021) explored how specific inquiry-related learning activities were related to student enjoyment of learning science and intended choice of future STEM careers. The data were from Taiwanese and Australian PISA 2015 results on three activities – debating and planning experiments, drawing conclusions and doing hands-on activities, and teachers and students explaining ideas. Taiwan and Australia were identified as sharing a consensus on developing scientific inquiry-related instruction to enhance the effectiveness of science education. The authors state that Taiwanese and Australian 15-year-old students have similar performances on science competency (4th and 14th out of 72 countries) but distinct cooperative behaviors – Taiwanese students emphasizing the product of cooperation compared to the Australian emphasis on the process of cooperation. Australian and Taiwanese high– and low–scientific competency students were compared across the three activities. Contrary to reports that inquiry activities are negatively associated with student learning outcomes, "this study identified specific inquiry-related activities that are beneficial to high and low scientific competency students in Australia and Taiwan" (p. 173).

Education for Sustainable Development (ESD) is required as part of the primary and high school curricula in Germany, and these aims can be achieved by introducing students to systems thinking. However, systems thinking is not part of university teacher education in Germany. In this study, Daniela Fanta et al. (2020) conducted a study with preservice biology and geography teachers to investigate the effect of three different interventions – a technical course, a mixed course, and a didactic course – that differed on the proportion of systems science and content for teaching systems thinking. The goal was to measure the extent of fostering systems thinking in student teachers of biology and geography in contrast to a control group. A heuristic structural competence model for systems thinking comprising four dimensions of competence was developed and used as the basis for a test

produced by the authors that was given to the preservice teachers. A quasi-experimental intervention study in a pre-, post-, and follow-up test control group design was employed and the instrument reliability, difficulty, and discrimination values provided. Upon completion of the courses, systems thinking was evident in all three courses compared to the control group. The authors concluded that "courses in fostering and teaching systems thinking should become part of the curricula in university teacher education, especially in the ESD-related topics such as biology and geography" (p. 240).

Common Features of Post-Positivist Research

Common Research Topics: The primary concern of 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 et al., 2002). Studies that typically are within a post-positivist paradigm include: (1) intervention studies, as seen in Ryoo and Linn's (2012) study and that of Fanta et al. (2020), and educational software studies such as the one by van Borkulo et al. (2012); (2) large-scale assessment studies, such as No Child Left Behind (NCLB) in the United States (Dee & Jacob, 2011), the National Assessment Program – Literacy and Numeracy (NAPLAN) in Australia (Dulfer et al., 2012), and the national competency study by Holstenbach et al. (2011); (3) international comparison studies, such as the Trends in International Mathematics and Science Study (TIMSS) (Thomson et al., 2012; Mullis et al., 2020) and the Programme for International Student Assessment (PISA) (Organisation for Economic Cooperation and Development, 2010; Thomson et al., 2016); and (4) secondary analyses, like those by Wang et al. (2021).

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 frequently choose experimental designs (Ryoo & Linn, 2012) or large-scale surveys (Velayutham et al., 2011) or interventions (Fanta et al., 2020). 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). However, this level of control is constrained because educational researchers are limited by ethical considerations and in this way use quasi-experimental designs. These researchers 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 addressed (Cohen et al., 2011). While qualitative data may be collected for such research designs through interviews, observations, or students' essays, the data are typically converted into numbers to correspond to pre-set categories (Ryoo & Linn, 2012) or used to support or elaborate on the quantitative data (Velayutham et al., 2011) as a form of triangulation.

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 et al. (2011) and Fanta et al. (2020), the same basic relationship was established between the researchers and the participants with no personal attachment with the participants. In the secondary analysis study by Hsin-Hui Wang et al. (2021), the researchers are far removed from the participants and the research sites.

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 [n.d.] 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., 2019).

Common Quality Standards: While many educational researchers characterize positivism/post-positivism in terms of rigorous research methods and verifiable data (Kincheloe & Tobin, 2009), D.C. Phillips (2005) argued 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: (1) a clear definition of concepts/constructs that are employed in the study; (2) a strong, logical reasoning throughout the research process – from literature review to interpretation of the empirical data to drawing of its conclusions; and (3) significant contribution of the study findings to educators or policymakers.

Common Report Styles: Most post-positivist educational 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 to give an impersonal, objective tone.

Interpretivist/Constructivist Research Paradigm

Philosophical Background and Theoretical Frameworks of Interpretivist/Constructivist Research Paradigm Studies

Interpretivism emerged as the reaction against the prevalent "scientific" positivism research. Different from post-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 the 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 post-positivists' effort to gloss over the specifics of the teaching and learning context to generalize their research findings. They argue that measuring and generalizing human understanding and behaviors – as in post-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, 1938/1988) regarding educational phenomenon. 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 the 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 and share 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 complete or the right one, but 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 may 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. Furthermore, as the researcher is often the instrument of interpretation, the researcher usually provides the reader with self-reflections on the research process and provides evidence of any real or perceived biases that may have been part of the interpretation process.

Examples of Interpretivist/Constructivist Research Studies

Similar to researchers in anthropology, science education researchers in the interpretivist/constructivist 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 with the participants, whom they study and from whom they collect large amounts of (mostly) qualitative data from observations, interviews, and descriptive narratives. 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 four examples are interpretivist/constructivist studies with which we are familiar that provide evidence of the variety of interpretivist studies. As with the selected post-positivist studies, these four studies are not the result of an exhaustive review of the literature.

An example of a more methodical interpretivist research position is one by David Treagust et al. (2001). The study explored how a middle school teacher used assessment embedded within her teaching the topic of sound. In conducting this case study, the researchers 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). One of the authors was the teacher of the class, and the rest of the researchers interacted with the students as observer participants. After three 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 et al. (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 scientific discourse 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, and how his drawings were admired by others, etc. 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 boy 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 students' negotiation of meanings could help their scientific sense-making.

What is taught in a genetics class depends on the teachers' perspective on teaching genetics – some content is required and other content is optional, so it is dependent on the teachers' willingness to teach it. In this qualitative case study, Tuomas Aivelo and Anna Uitto (2019) conducted open-ended semi-structured interviews with ten upper-secondary high school biology teachers in Finland to learn how these teachers justified their choices for content and contexts when teaching genetics. The teachers were specifically asked how they teach and what examples they used on three different human-related contexts: genetically modified organisms (GMOs), human hereditary disorders, and human complex traits, such as intelligence. These three contexts functioned as a gradient in terms of how much freedom teachers had to choose what content and contexts they taught, with GMOs being part of the national core curriculum. Interviews lasted for 40 to 92 minutes. The teachers' responses were categorized using a theory-guided content analysis. Trustworthiness of the data was based on teachers recording details of their teaching and the questions that students asked or for answers that needed clarification. Teachers' discussion of the content taught was divided into three themes, and how they taught the use of GMOs and human genetics and dealt with controversial or

sensitive issues in genetics. The analysis showed that there were fundamental differences in these biology teachers' perceptions of the most important themes in genetics and genetics teaching and hence what was taught. While many of these Finnish teachers discussed human traits and other sensitive issues, the researchers argue that the teachers would need more curriculum support to handle controversial and sensitive issues in the classroom. GMO was the most taught topic by all teachers, being specifically mentioned in the curriculum.

Heidi 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 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. 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 in the paper to demonstrate the subtle way the participants' experiences are integrated into their way of communication 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.

Consistent with recent policy initiatives in the United States, the goal of this study was to explore and further elucidate secondary teachers' knowledge of students' conceptions on the topic of evolution by natural selection. In this research, Margaret Lucero et al. (2020) conducted teacher interviews – using items from a known questionnaire as prompts, collected students' artifacts and video recorded classroom observations. The research design employed a qualitative grounded theory approach to analyze data collected from four high school biology teachers. Recognizing that many US students hold non-scientific explanations about evolution and natural selection, the researchers interviewed the teachers prior to and after formal instruction on evolution. Data from the videoed classroom observations and the students' artifacts triangulated with the teacher interviews generated 18 concepts through open coding of the data, reconciliation of tentative categories and axial coding to establish the trustworthiness of the data. Five broad categories were identified, two confirming prior research – about students' understanding of ecological and genetics concepts and students' default ways of thinking – and three providing new ideas – related to students' experience of the topic, non-science issues such as lack of vocabulary that may affect understanding, and students' test-taking strategies. The authors argue that the findings provide a better understanding of secondary students' understanding of evolution that can help address reform-oriented instruction.

Common Features of Interpretivist Research Studies

Common Research Topics: Interpretivist studies focus on the cultures (Carlone, 2004), language use (Warren et al., 2001), teachers' decisions about content and contexts (Aivelo & Uitto, 2019), teachers' knowledge of students' conceptions (Lucero et al., 2020), classroom interactions (Gallas, 1995;

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 sensemaking process for the researchers involved, the research design itself can evolve, as illustrated by studies using grounded theory (Lucero et al., 2020). 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 something that would be frowned upon in post-positivist research, but is a natural process of interpretivist research. Interpretivist/constructivist researchers tend to adopt qualitative research designs, such as case study, ethnography, narrative, and phenomenological research (Carlone, 2004). 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 pre-given but are co-created through hermeneutic dialogues (Schwandt, 2000), researchers often aim to study by engaging with the activities of the research participants (Aivelo & Uitto, 2019; Clandinin & Rosiek, 2007; Guba & Lincoln, 2005; Lucero et al., 2020; 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 to immerse in the situation to experience the situation 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 sensemaking process. Frederick Erickson (Moss et al., 2009) categorizes the criteria to judge quality interpretivist research study into two: the technical aspects and the educational imagination. Technical aspects involve: (1) prolonged, meaningful interaction in the field; (2) careful, repeated sifting through the data; (3) reflective analysis of the data; and (4) 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; affects readers through resonance; 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 we 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 (Aivelo & Uitto, 2019; Carlone, 2004; Lucero et al., 2020). Or it could take a story-like format of describing a daily procedure of a schoolteacher or children's discussion in class (Gallas, 1995, 1997). In such story-like reports, some researchers do not make a long validity claim or methodological justification; they simply describe what they have done and explain why. Other researchers use member checking, follow audit trails, and other measures as a way to ensure that researchers are interpreting and communicating research participants' perspectives fairly and reflectively. 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 weaved 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 on 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 data analysis, and how they considered alternative interpretations. However, the research by Munoz-Najar Galvez et al. (2020) that analyzed 137,024 dissertation abstracts in the field of education from 1980 to 2010 showed that "topics associated with the interpretive approach rose in popularity while the outcomes-oriented paradigm declined" (p. 612). This detailed analysis of educational research abstracts is consistent with science education research articles where sociocultural, interpretivist research studies appear more frequently in major science education journals. In addition, *Cultural Studies in Science Education*, established in 2006, 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.

Critical Theory[1] Research Paradigm

Philosophical Backgrounds and Theoretical Frameworks of Critical Theory Research Paradigm Studies

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 as 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 et al., 1996)? Twenty years ago researchers were asking questions such as: 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 to learn science at school (Aikenhead & Jegede, 1999; Brickhouse et al., 2000; Harding, 1991)? Research has provided answers to many of these questions, leading to further questions about how to maintain females' interest and engagement in science (see, for example, Prieto-Rodriguez et al., 2020; Stevenson et al., 2021).

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). Critical researchers ask themselves how they should change, as teacher, educational researcher, and concerned community member, for society to be more equal, open, and democratic (Bouillion & Gomez, 2001; Elmesky & Tobin, 2005; Roth & Desautels, 2002; Tan & Barton, 2008). In order to enact changes in the lives of the socially, economically, and historically marginalized people, researchers often spend time in low-income, ethnic minority neighborhood schools and become involved in some type of action research project.

Examples of Critical Theory Research Studies

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 following five examples are critical theory studies with which we are familiar that provide evidence of the variety of elements in such studies. As with the selected studies in the post-positivist and interpretive research, these five studies are not the result of an exhaustive review of the literature. The first two studies by Bouillion and Gomez (2001) and by Elmesky and Tobin (2005) illustrate how science education researchers attempted to change how schooling or social research is conducted. The researchers first pointed out the limitations of the status quo and then enacted alternative ways. Their primary goal was not only to observe but to change the situation and empower the students and their community for the betterment of the people involved. The third study by Tan and Barton (2008) was conducted in the same vein as the first two, but their study may look very similar to an interpretivist study in terms of their defense of research methods, presentation of results, and interpretations. The fourth study, by Eisenhart (2000), is a critical autoethnographic study where 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. The fifth study, by Hoeg and Bencze (2017), illustrates how government policy statements for STEM education are based on embedded practices that benefit and privilege certain people as effective citizens and the statements are not criticized. The five studies briefly summarized next 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 by 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 to make the action project successful. Here, the research report format is not much different from interpretivist research studies but has the important element of political orientation challenging the status quo. However, the focus of the study was not simply reporting a successful science activity. The researchers aimed to change the existing practice of science teaching at 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 actively incorporated into the activity planning and execution; between education researchers and school teachers as they became equal contributors in the collaborative project; 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. Instead of following the conventional model of objectifying students' ideas, Rowhea Elmesky and Kenneth Tobin (2005) involved students as the collaborative researchers rather than as subjects trying to change the power imbalance in the research process. 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 Kincheloe and 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 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 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 "problems" or "failures" and by depriving learning opportunities to make meaningful personal connections to science. After a discussion of the feminist stance on the global knowledge economy, the researchers carefully described how two sixth grade ethnic minority girls from a low-income neighborhood community 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 a critical auto-ethnographic, 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/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 of the 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 why 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 of what happened to the larger social discourse eased her guilty conscience to her co-author and showed off an academic's intellectual power. This reflective, honest piece of writing leads us to reconsider the meaning of what we do and how we do it in a new light.

The importance of science, technology, engineering, and mathematics education – collectively known as STEM education – for preparing citizens for the future is readily accepted by most nations. In the United States policy guidelines have been developed in STEM education. In their article, Darren Hoeg and Larry Bencze (2017) raise issues with the manner in which these policy guidelines are presented and critically discuss the "biopolitics in science education, notions of citizenship in contemporary school education and science education and citizenship and STEM Education" (p. 844). The review identified themes and categories that became the basis of critical discourse analysis based on Foucault's (2003) stages of biopolitical development associated with human action and practice. The authors illuminated the ways in which powerful social practices are embedded in the construction of STEM policy and education. They argue that these policy statements are designed to create positive attitudes toward solutions that prioritize and privilege citizen subjectivity such that responses are positive to STEM initiatives and little criticism is engendered. The dominant way of speaking in this discourse is that a scientifically literate citizenship represents "progress". The discourse connects scientific literacy with effective citizenship – namely, those who participate effectively, implying that other citizenship roles and types of citizens are not as important to the problems that threaten a nation and specifically the economy.

Common Features of Critical Theory Research Studies

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 the multiple, subtle ways that discourage or marginalize the participation of socially disadvantaged people in schooling or science (Elmesky & Tobin, 2005) or challenges to policies that prioritize and privilege some citizens over others (Hoeg & Bencze, 2017). The study of power relationships is a common research topic. As an example, Teo and Tan (2020) provided a critical analysis of power, knowledge, and power relationships between a chemistry expert – the school-based School Scientist – and two apprentices – two students in Grade 10 and another in Grade 9) – in a chemical synthesis project. "This study shows teaching and learning in the form of an apprenticeship model involved dynamism in the negotiations of power relationships during the apprenticeship process" (p. 672–673).

Common Research Designs: The designs of critical theory research are often very similar to 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 relations 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) are examples of such studies.

Role of the Researcher: The main goal of research is not about expanding the body of knowledge but about challenging the given status quo with the aim of transforming the society and institution for the betterment of the people involved (Hoeg & Bencze, 2017). Rather than writing as a distant, unbiased scholar, critical theory researchers claim they are intellectuals and activists, working for social justice and for the people who are socially and politically disempowered (Fine et al., 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 relationships with research participants, democratic decision-making, and shared contributions to the study), and the social impact of the study in transforming society (e.g., greater/sophisticated understanding of the society, the empowerment of the participants, and prompting or enacting changes in social/personal practices) (G. Anderson et al., 1994; Griffiths, 1998).

Common Report Styles: Because they are consciously problematizing what is given or conventional, the authors intentionally do not follow the traditional fabric of a research report. Instead, they experiment with the reporting of the study, such as adopting a performance or writing the story as fiction (Flores-González et al., 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 Tan and Barton (2008) and by Eisenhart (2000).

Mixed-Methods Research Paradigm

Discussions about research paradigms often result in responses like, "Research paradigms do not matter anymore" and "We can mix and match multiple paradigms to answer research questions". While it is true that research studies do need to address the research questions thoroughly, and some researchers use both quantitative and qualitative data, can we really mix and match research paradigms? How can realism (positivist), relativism (interpretivist), and feminism (critical theory) as worldviews be integrated into a research study? How can a researcher be a distant scientist (positivist) without direct connection to research participants and at the same a passionate interpreter (interpretivist) and advocate (critical theory) of research participants with intimate knowledge of their lived experiences?

To many contemporary education researchers, research paradigms are not considered complex belief systems with philosophical underpinnings and practical implications. Rather, paradigms are regarded the same as research methods or designs. According to Cohen et al. (2017), researchers such as Creswell and Plano Clark (2011) appear to make the distinction linked to types of data – post-positivism (quantitative research), constructivism (qualitative research), participatory/transformative (qualitative research), and pragmatism (quantitative research and qualitative research). Alise and Teddlie (2010) also identified a strong tendency for post-positivist researchers to use quantitative methods and for interpretivist and critical theory researchers to use qualitative methods. Many researchers do not regard paradigms as complex belief systems, and they do not see any problems mixing quantitative and qualitative data in a research study. Mixed-methods researchers believe that dichotomizing quantitative and qualitative data is not only unproductive but fallacious (Ercikan & Roth, 2006). As researchers tend to focus on practical aspects of research design and methods rather than worldviews or paradigms when designing and executing research, some researchers question the practical value of research paradigms anyway (Morgan, 2007). Others (e.g., Greene, 2008) focus on the practical value of a problem-solving approach without the restrictions of theory. Discussions about the relationship between paradigms and data types is an ongoing issue.

As Bryman (2008) notes, combining different research methods is an area where researchers still have different views. While many post-positivist researchers welcome such adjustment as a way to increase the validity of research findings, constructivist researchers are rather critical of such approaches. Denzin and Lincoln (2011), for example, regard mixed methods as a remnant of positivist legacies that relies on numbers as scientific evidence, resisting to acknowledge the value of interpretivist qualitative studies and the political issue of what counts as evidence.

Without an explicit philosophical framework and guiding principles within it and conflating research paradigms with methods, the mixed-methods approach is a different way of framing research compared to the other three research traditions. Nevertheless, we decided to include mixed methods as the fourth paradigm, despite our initial reservation against it. In many ways, discussion of the mixed-methods approach relates to our earlier comments about Kuhn's discussion of the invisibility of paradigms where researchers do not consider the history that frames their current practice. This tendency to ignore historical and philosophical considerations such as paradigms when designing and discussing our research is a limitation of the reported research. For a brief comparison of four different research traditions, please see Table 1.1.

Table 1.1 Similarities and Differences of Common Features Between the Four Paradigms

Common Features	*Post-Positivist Research Studies*	*Interpretivist/ Constructivist Research Studies*	*Critical Theory Research Studies*	*Mixed Methods Research Studies*
Research Topics	Evaluation of effectiveness/ efficiency of intervention teaching programs Large-scale assessments or surveys	Lived experiences of teachers and students with focus on culture, language use, and daily classroom/school interactions	Political and historical aspects of education Lived experiences of disadvantaged population to highlight educational inequality Activist movement to challenge the status quo	Evaluation of effectiveness/ efficiency of intervention teaching programs
Research Designs	Explanatory designs (e.g., experiment or survey research) with representative sampling, quantitative measurement, and multiple validation processes of data	Exploratory designs (e.g., grounded theory, ethnography, phenomenology research) in naturalistic settings with evolving research methods involving thick description	Similar to interpretivist studies or participatory action research with explicit emphasis on social ideologies and power relationships	Explanatory or exploratory mixed-methods research designs
Role of the Researcher in Relation to the Participants	Objective, unbiased collector and interpreter of data without close connection to research participants	Insightful and passionate meaning maker and storyteller of research participants' lived experiences	Strong advocates of the socially marginalized to challenge status quo	Objective data collector and interpreter with some connection to research participants
Quality Standards	Clear definition of constructs/concepts Rigorous research methods for objective, comprehensive data Reliability of measurement Internal and external validity of knowledge claims	Prolonged meaningful interaction in the field and repeated re-analysis and reflections on data Depends on researcher's skills, sensitivity, and integrity Member check, audit trail, peer review, triangulation	Democratic and catalytic value of the research	Comprehensive answer to the research questions
Report Styles	Traditional scientific research format, written in third person	Use of thick description Can be as a traditional empirical study Or as storytelling, weaving participants' lived experience with researchers' interpretations	Consciously problematizing what is given or conventional. Some researchers write a fictional story, others more traditional ethnographic reports	Similar styles as in post-positivist studies with participants' interview quotes

Examples of Mixed-Methods Studies

Next, we present five studies that adopt mixed-methods approaches, providing readers with the types of data collected and how these are analyzed in mixed-methods research studies. As noted in Table 1.1, mixed-methods researchers' reports have the main features of reports by researchers using post-positivist and interpretivist paradigms but, as already stated, have essentially ignored the philosophical and epistemological frameworks or backgrounds.

Using an overtly described two-phase, sequential mixed-methods study, Sedat Ucar et al. (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 semi-structured 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 or not 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 post-instruction 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; fossilization of geochemistry remained problematic for both groups.

Vaughan Prain and Bruce Waldrip (2006) conducted research with a group of teachers and their Year 4–6 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 qualitative 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 multi-modal focus. The data included classroom observations and interviews with students when they were involved in classroom activities. Two science classes were reported.

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.

In a similar manner, using a mixed-methods study described as a quasi-experimental control group design with a pre- and post-test questionnaire involving both quantitative and qualitative data collection and analysis procedures, Emine Adadan (2020) investigated the role of metacognitive awareness in preservice chemistry teachers' level of understanding of gas behavior in a multi-representational instruction setting. The quantitative data were from a survey administered to a group of 34 preservice teachers and qualitative data from an open-ended questionnaire. Reliability measures for the quantitative data were reported, and the qualitative responses were coded using the constant comparative method. The results were reported in response to three research questions, and the numerical and interpretive data analyses provided consistent and integrated evidence (p. 271). Similar to other related studies, "the participants with high metacognitive awareness appeared to outperform the participants with low metacognitive awareness in terms of developing a more scientific understanding of gas behaviour immediately after the multi-representational instruction" (p. 271).

Common Features of Mixed-Methods Research Studies

Common Research Topics: Mixed-methods studies involve a wider range of research topics, from an evaluation of a teaching intervention with some research participants' insights integrated into the research report, to a case study of classroom interactions and dialogues with some complementary quantitative measures.

Common Research Designs: Creswell's (2012) common mixed-methods designs, both explanatory and exploratory, are adopted so long as quantitative and qualitative data are used in a complementary manner. These designs encompass post-positivist researchers adding qualitative data, such as short interviews or field notes, to a quantitative experimental research design, as seen in Ucar et al. (2011) and Clary and Wandersee (2007). They also include interpretivist researchers borrowing quantitative techniques, such as achievement test scores or survey results, to a case study design, as seen in Hohenshell and Hand (2006) and Prain and Waldrip (2006).

Common Quality Standards: One of the justifications of mixed-methods approaches is that the mixed use of quantitative and qualitative data enables a thorough triangulation of the data to make stronger knowledge claims (Creswell, 2012; Mathison, 1988; Reeves, 1997).

Role of the Researcher and Common Report Styles: As mixed-methods researchers use the methods from the other three paradigms, the role of the researcher and the reporting styles are similar to those described for the other three paradigms.

Conclusion

Science education researchers have strived to establish solid knowledge claims in 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 this chapter, we have described four distinctive research traditions, identified relevant studies, and highlighted commonly shared features within each tradition. Our aim has been to show how a research paradigm frames the 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.

The landscape of conducting research within these paradigms has gradually changed over the years, though all paradigms, in keeping with the ideas of Thomas Kuhn, are largely hidden from

view. In the years ahead, we can imagine that approaches to research will continuously evolve to incorporate new issues and ideas. We hope this review will contribute to productive discussion by science education researchers working within and across these four different research paradigms in science education.

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Note

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

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