Handbook of Research on Science Teacher Education

Edited by Julie A. Luft and M. Gail Jones

Routledge

HANDBOOK OF RESEARCH ON SCIENCE TEACHER EDUCATION

This groundbreaking handbook offers a contemporary and thorough review of research relating directly to the preparation, induction, and career long professional learning of K–12 science teachers.

Through critical and concise chapters, this volume provides essential insights into science teacher education that range from their learning as individuals to the programs that cultivate their knowledge and practices. Each chapter is a current review of research that depicts the area and then points to empirically based conclusions or suggestions for science teacher educators or educational researchers. Issues associated with equity are embedded within each chapter. Drawing on the work of over 100 contributors from across the globe, this handbook has 35 chapters that cover established, emergent, diverse, and pioneering areas of research, including:

- Research methods and methodologies in science teacher education, including discussions of the purpose of science teacher education research and equitable perspectives;
- Formal and informal teacher education programs that span from early childhood educators to the complexity of preparation, to the role of informal settings such as museums;
- Continuous professional learning of science teachers that supports building cultural responsiveness and teacher leadership;
- Core topics in science teacher education that focus on teacher knowledge, educative curricula, and working with all students; and
- Emerging areas in science teacher education such as STEM education, global education, and identity development.

This comprehensive, in-depth text will be central to the work of science teacher educators, researchers in the field of science education, and all those who work closely with science teachers.

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Routledge
Taylor & Francis Group
NEW YORK AND LONDON

Cover image: © Getty Images

First published 2022
by Routledge
605 Third Avenue, New York, NY 10158

and by Routledge
4 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN

Routledge is an imprint of the Taylor & Francis Group, an informa business

Library of Congress Cataloging-in-Publication Data
Names: Luft, Julie, editor. | Jones, M. Gail, 1955- editor.
Title: Handbook of research on science teacher education / edited by Julie A. Luft and M. Gail Jones.
Description: New York, NY : Routledge, 2022. | Includes bibliographical references and index.
Identifiers: LCCN 2021050930 | ISBN 9780367565831 (hardcover) | ISBN 9780367565824 (paperback) | ISBN 9781003098478 (ebook)
Subjects: LCSH: Science teachers—Tranining of. | Science—Study and teaching.
Classification: LCC Q181 .H1495 2022 | DDC 507.1/2—dc23/eng/20211217
LC record available at https://lccn.loc.gov/2021050930

ISBN: 9780367565831 (hbk)
ISBN: 9780367565824 (pbk)
ISBN: 9781003098478 (ebk)

DOI: 10.4324/9781003098478

Typeset in Bembo
by Apex CoVantage, LLC

This book is dedicated to science teachers who graciously opened and open their classrooms to collaborate with science teacher educators and researchers. Every time we work together, we learn together.

Advisory Committee for the *Handbook of Research on Science Teacher Education*

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Christa Haverly is a postdoctoral researcher at Northwestern University, USA. Her research focuses on supporting elementary teachers in science instruction both from a practice-based approach, considering students' sensemaking and teachers' responsiveness, as well as from a systems-building approach, considering how school systems can organize to support instructional improvements in elementary science. She is particularly interested in examining these issues through an equity lens that moves beyond access and opportunities for student learning to consider the ways that school systems, schools, and teachers make space for students to claim epistemic agency in the elementary science classroom. Haverly has published in *Cognition and Instruction* and *Journal of Teacher Education*, among other venues.

Sara C. Heredia is Assistant Professor of Science Education in the School of Education at the University of North Carolina at Greensboro, USA. Her research focuses on the design of professional learning opportunities that engage secondary science teachers in experiences that support them in facilitating student sensemaking in their classrooms. In particular, she focuses on the ways in which teachers' school and district contexts matter for how they make decisions about reform implementation. She works in partnership with teachers, schools, and informal science institutions to create a network of support for implementation of science education reform. Her work has been published in research journals including *Science Education* and the *Journal of Science Teacher Education*, as well as practitioner journals such as *Science Scope* and *Connected Science Learning*.

Rebecca Hite is Assistant Professor of Science Education in the Department of Curriculum and Instruction at Texas Tech University, USA. Her research studies focus on curricular and instructional interventions, augmented by emerging technologies, that occur within in/formal learning spaces as well as professional pathways for K–12 STEM teacher leadership in policy-advocacy. Hite is on the editorial board for the *Journal of Interdisciplinary Teacher Leadership* (2015–present), the *Journal for Research in Science Teaching* (2019–22), and the *Journal of Science Teacher Education* (2020–23).

Linda Hobbs is Associate Professor of Education at Deakin University, Australia. Hobbs's research focuses on teaching out-of-field, partnerships in science teacher education, STEM, and science education, and she works with schools and teachers in a range of capacities through professional development, student programs, and research. Her most recent work has focused heavily on the various aspects of the out-of-field teaching phenomenon, particularly on the experiences of teachers who teach mathematics and science out-of-field. Her recent research funded internally is exploring the subject-specific nature of teaching out-of-field, the pedagogy of STEM professional development, and evaluation in education research.

Elaine Howes is a faculty member in education in the American Natural History Museum's (AMNH) Master of Arts in Teaching (MAT) Earth Science Residency Program, USA. Dr. Howes's work includes studying her own teaching, and teaching and collaborating with preservice and in-service science teachers, has led to publications about teachers' practices in working with English-language learners in science, and the challenges involved in developing environmentally and culturally relevant science curriculum for urban K–12 classrooms. Her current research examines how teacher education programs support new teachers in learning about their students' ideas, communities, and cultures, and how they use what they learn to inform their science teaching. As a member of the AMNH MAT faculty, she is continuing her commitment to working with teachers to develop science education that supports all students in succeeding in science in high-need schools.

Ying-Shao Hsu is Professor in the Graduate Institute of Science Education and the Department of Earth Sciences, as well as Chair Professor of National Taiwan Normal University, Taiwan. She received her PhD degree in 1997 from the Department of Curriculum and Instruction at Iowa State University. Her research focuses on e-learning and teaching, inquiry learning, science curriculum design, metacognition, social-scientific issues, and STEM education. Professor Hsu's research work has been recognized with Outstanding Research Awards by the Minister of Science Technology (MOST) in Taiwan (2011, 2015), National Science Council Reward Special Talents (2010, 2011), National Taiwan Normal University Research Awards (2005, 2006, 2007, 2008, 2012, 2015), and the Wu Da-Yu Memorial Award (2005).

Mercè Izquierdo is an Emeritus Professor at Universitat Autònoma de Barcelona, Spain. She obtained a bachelor's degree in chemistry at the Universitat de Barcelona, and a PhD in science at the Universitat Autònoma de Barcelona. She worked as a secondary chemistry teacher and also as a chemistry university lecturer before being involved in science teacher education and science education research. Her current research interests are history and philosophy of science, modeling and language, and chemistry education within the contexts of secondary education and science teacher education. During her career, she has contributed to incorporating science education as part of primary and secondary teachers' education, and to consolidating science education as a research field in Spain and Latin America. She has also made significant theoretical contributions to models and modeling as a science learning perspective, and regarding the contributions of history and philosophy of science-to-science education.

David F. Jackson is Associate Professor of Science Education at the University of Georgia, USA, where he teaches in the Secondary Science teacher certification program, has been in charge of the science aspects of the Middle Grades teacher certification program for 32 years, and previously served as Graduate Coordinator for 13 years and as Associate Department Head for 3 years. He teaches a preservice course held in middle school classrooms and planned in cooperation with practicing middle school teachers, most often at the 8th-grade level. He recently designed and developed UGA's online MEd in science education program. The primary foci of his research efforts have been the use of electronic technologies and simulations in science teaching; cognitive, cultural, and political issues in the teaching of biological evolution and historical geology; and all aspects of middle-grades science teaching and teacher education.

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Sami Kahn is Executive Director of the Council on Science and Technology at Princeton University, USA. Dr. Kahn uses her background in science education and law to inform her research on inclusive science practices, socioscientific issues (SSI), argumentation, and social justice. An award-winning science educator, teacher educator, and author, she currently serves as Chair of the Inclusive Science Education Forum for the Association for Science Teacher Education (ASTE) and Co-Editor of the *Journal of Science Education for Students with Disabilities.* Her former posts include serving as Chair of the National Science Teaching Association's (NSTA) Special Needs Advisory Board and President of NSTA's associated group, Science Education for Students with Disabilities (SESD). Dr. Kahn holds an MS in ecology and evolutionary biology from Rutgers University, a JD in law from Rutgers School of Law, and a PhD in curriculum and instruction with a specialization in science education from the University of South Florida, where she served as a Presidential Doctoral Fellow.

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Kelly L. Knight is Associate Professor with the George Mason University Forensic Science Program and a STEM Accelerator, USA. As a STEM Accelerator, she mentors STEM students and leads K–12 STEM outreach programs. She is the co-founder and director of Females of Color and those Underrepresented in STEM (FOCUS), a program which makes STEM exciting and accessible for BIPOC (Black, Indigenous, and people of color) girls. Professor Knight is also currently working on her doctorate in science education research at George Mason. Her research examines how out-of-school STEM programs impact BIPOC girls, particularly in the area of STEM identity. Through her advisory roles and participation in various diversity, equity, and inclusion committees across campus, such as the President's Anti-Racism and Inclusive Excellence taskforce, Professor Knight's work in higher education centers on the development and implementation of equitable practices for both STEM students and faculty. She recently received the 2020 University Teaching Excellence Award.

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Kassandra L'Heureux is a graduate student at Université de Sherbrooke, Canada. She is interested in the contextualization of science learning and teaching inside and outdoor teaching and learning in schools' immediate surroundings. She is also interested in the development of critical thinking in the context of socioscientific topics, including the context of the pandemic. Her master's project focuses on the methods and strategies used to contextualize learning for future elementary and secondary science teachers. Her work is supervised by Professor Jean-Philippe Ayotte-Beaudet and Professor Abdelkrim Hasni. She used to work in orthopedagogy in high school. She is a lecturer at the Université de Sherbrooke, Canada, in Didactics of Science where she teaches to 1st- and 3rd-year undergrad students.

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Julie A. Luft is a Distinguished Research Professor, Athletic Association Professor of Mathematics and Science Education, and Adjunct Professor of Biochemical and Molecular Biology at the University of Georgia, USA. Dr. Luft's studies have explored science teacher development, professional development, and recently leadership. She has awards for her research and practitioner studies and for her teaching and mentoring of graduate and undergraduate students. She is a Fellow of the National Science Teaching Association (NSTA), American Association for the Advancement of Science and the University of Georgia Owens Institute of Behavioral Research. She has been an Associate Editor of several journals including the *Journal of Research in Science Teaching*, President of the Association of Science Teacher Education, an NSTA scholar-in-residence, and a Fulbright Specialist. She has testified about inquiry instruction to a US congressional subcommittee and served on the National Academies of Sciences, Engineering, and Medicine committee on the professional learning of science teachers.

Mariana Luzuriaga is a research assistant and Assistant Professor at the University of San Andrés, Argentina. She has a bachelor's degree and a postgraduate teaching qualification in education, and is currently a PhD candidate at the University of San Andrés, Argentina. Since 2014 she has been a member of the Science Education Program at the same university, participating in various research and professional development projects related to science teaching at all educational levels. She has co-authored books, academic papers, and curriculum materials in the field, including the design of science teacher professional development courses within the National Teacher Training Program in Argentina. Her current research interests revolve around the planning and decision-making processes of primary-level teachers, and the ways in which these relate to curriculum policies and materials.

Edward G. Lyon is Associate Professor of Science Education at Sonoma State University, USA. Dr. Lyon researches how science teachers learn and enact core instructional and assessment practices that integrate inquiry-based science with language and literacy development for emergent bilinguals. He also co-directs the Sonoma State STEM Teacher Education Pathways Center. He has published in leading science education journals, authored the book *Secondary Science Teaching for English Learners: Developing Supportive and Responsive Learning Contexts for Sense-Making and Language Development*, and co-led the NSF-funded Secondary Science Teaching with English Language and Literacy Acquisition (SSTELLA) Project. He has served as an editorial board member for the *Journal of Research in Science Teaching and the Journal of Science Teacher Educator*. He earned his PhD in science education from the University of California, Santa Cruz and received the UC/ACCORD Dissertation Fellowship, the CCTE Outstanding Dissertation Award, and the NARST Outstanding Paper Award in 2012.

Lauren Madden is a Professor of Elementary Science Education at The College of New Jersey, USA, where she also coordinates the Environmental Sustainability Minor and Graduate Certificate programs. Her mission is to advocate for scientific literacy and the health of our planet through teaching and learning. She has published more than 40 peer-reviewed articles and book chapters, and has a textbook on science teaching methods due out in 2022. Her current research focus is on developing teachers' content knowledge and confidence in marine science, climate change, and the effective use of the NGSS. Her work has been funded by the New Jersey Sea-Grant Consortium, the US Environmental Protection Agency, and the National Science Foundation. In 2021, she was recognized as the Association for Science Teacher Education's Outstanding Science Teacher Educator of the Year and NJ STEM Pathways' inaugural iCAN STEM role model.

Rachel Mamlok-Naaman served as Head of the National Center for Chemistry Teachers until September 2020, and until June 2016 she was the Coordinator of the chemistry group at the Weizmann Institute, Israel. Dr. Mamlok-Naaman was the coordinator of a special master's program for chemistry teachers, and of projects in the framework of the European Union in Israel. In addition, she is the chair of EuCheMS DivCED, an ACS titular member, and serves on editorial and advisory boards of science education journals and organizations. Her publications focus on topics related to curriculum development, student learning, and teachers' professional development.

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Felicia Moore Mensah is a Professor of science education, and Department Chair of Mathematics, Science, and Technology at Teachers College, Columbia University, New York, USA. Dr. Mensah has published extensively, where her work addresses issues of diversity, equity, and identity in science education. Her most recent research utilizes critical race theory and intersectionality to transform teacher education research and practice. Her work on the experiences of Teachers of Color and preparing future teacher educators for racial literacy combines years of teaching, mentoring, and outreach. Dr. Mensah was the recipient of the 2017 Outstanding Science Teacher Educator of the Year (ASTE); the 2012 Early Career Award, Division K Teaching and Teacher Education (AERA); and an Equity and Ethics Scholar in 2005 (NARST). Dr. Mensah is a Past President of Sisters of the Academy Institute, or SOTA, an organization that supports the success of Black women in higher education. Among other activities, she is co-editor of the *Journal of Research in Science Teaching* (*JRST*).

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Sabela F. Monteira is an educational researcher at the SciTeach Center at the University of Luxembourg, Luxembourg. Her work focuses on the collaborative creation of resources for promoting science teaching and learning during the early ages, as well as for supporting the development of creative spaces for engaging in science. She is also a preservice teacher educator (PhD, ed., Universidade de Santiago de Compostela, Spain) and former chemist (BSc, chemistry, University of Glasgow, Scotland). Her research uses ethnographic methods in order to investigate the multiple ways through which young children and their teachers collectively engage in inquiry along the first 3 years of formal schooling. Her work focuses on how children's engagement in the disciplinary practices of science evolves from 3 to 6 years of age and on how teachers foster the development of children's communication and representational skills, as well as cognitive and affective scaffolding strategies that promote increasing children's autonomy.

Patricia Moreira is a natural science and chemistry teacher in Chile. She received her PhD in science education at the Pontificia Universidad Católica de Chile (Chile) in 2019. Moreira has 6 years of experience teaching at both middle and high school levels in Chile, and the last 6 years as a teacher educator at Pontificia Universidad Católica de Chile. The principal goal of her research is to provide evidence to understand and enhance the teaching and learning processes in science education through the characterization of the expressed scientific reasoning of middle school and high school students, and by identifying how classroom interactions shape students' expressed reasoning.

Audrey Msimanga is Associate Professor of Science Education and Head of the School of Education at the University of the Witwatersrand, South Africa. Audrey has worked in biology research, science education research, and teacher education for over 30 years. Audrey's research seeks to understand the challenges and affordances of access to science and success in science education for English second-language students in sub-Saharan Africa. Audrey is currently Associate Editor for the *Journal for Research in Science Teaching* (JRST), a member of the Editorial Board of the European Science Education Research Association (ESERA) Book Series, and President-Elect of the Southern African Association for Research in Mathematics, Science and Technology Education (SAARMSTE).

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Meshach Ogunniyi is Emeritus Professor at the University of the Western Cape, South Africa. His research interests straddle NOS, IKS, and the integration of the two using an argumentation instructional model. He has written over a dozen books and published over 200 articles in refereed journals, conference proceedings, and book chapters. He has supervised over 80 master's and doctoral theses and has conducted several large-scale studies. He retired first in 2009 and finally in 2014. He has served as an editor and member of editorial boards of several journals. He received the Vice-Chancellor Best Teacher Award in 2008, a Life-time Research Award of SAARMSTE in 2014, and the NARST Distinguished Research Award in 2015.

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José Manuel Pavez is a doctoral student at the University of Georgia, USA. Originally from Chile, he graduated from the Metropolitan University of Educational Sciences, Santiago, Chile. He has over 10 years of teaching experience from 5th grade to the graduate level in Chile and the USA. He has been actively involved in educational research since 2012. His research interest has been around science teacher education, nature of science, and science methods courses. He has participated in different research projects funded by NSF and FONDECYT (Chilean state funds). He has served multiple local and international organizations like NARST, ASTE, and SCHEC, as well as many journals in science education, like the *Journal of Science Teacher Education* (JSTE), where he is part of the editorial review board. His efforts were recognized by the ethics and equity panel of NARST, who named him a Jhumki Basu fellow in 2021.

William (Bill) Penuel is Professor of Learning Sciences and Human Development in the School of Education and Institute of Cognitive Science at the University of Colorado, Boulder, USA. His research focuses on interest-related learning across settings, classroom assessment in science, teacher learning, and promoting the equitable implementation of reforms in STEM education. As Principal Investigator for a U.S. Department of Education knowledge utilization center, the National Center for Research in Policy and Practice, he studies how school, district, and state education leaders use research evidence in decision-making. He has been involved in research-practice partnerships at the district and state levels, focused on supporting implementation of the Next Generation Science Standards through co-design of curriculum and assessment resources that connect to students' interests, identities, and experiences. He is a Fellow of the International Society of the Learning Sciences, American Educational Research Association, the International Society for Design and Development in Education, and the National Education Policy Center. He is also an elected member of the National Academy of Education and member of the Board on Science Education at the National Academy of Sciences, Engineering, and Medicine.

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Neal Petersen is Deputy Director in the School of Mathematics, Science, and Technology Education at North-West University, South Africa. His research interests focus on using engaging pedagogies to contextualize science teaching including indigenous knowledge, STEAM education, cooperative learning, self-directed learning, and teacher professional development. He was the principal investigator of a project on using engaging pedagogies and is currently a co-investigator in a Fuchs Foundation-funded project, "Teachers without Borders," with a focus on empowering in-service science teachers to use engaging pedagogies. He acts as supervisor and co-supervisor for various postgraduate students, has published in national and international publications, is the co-editor of a AOSIS book, and has presented papers at national and international conferences.

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David Santibáñez is Professor of Science Education at Finis Terrae University. He is Public Policy Director of the Chilean Society of Scientific Education (SChEC), of which he is one of its founders. He has vast experience as a biology teacher in elementary, middle, and university education. He is the author and advisor of numerous textbooks and a consultant for national teacher evaluation agencies in the area of science. He is a researcher in FONDECYT (Chilean state funds) projects related to the training of science teachers, the nature of science, and pedagogical knowledge content (PCK). He has recently participated in the publication of the book *Teaching Evolution and Genetics for Scientific Literacy*. David's main interest is related to the training of elementary teachers, especially the process that allows them to develop their PCK in science.

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PREFACE

The idea for this book began with a friend, Patricia (Pat) Friedrichsen. In discussing our final years in science teacher education, we shared the important contributions we hoped to make in the field. Our discussion meandered through research contributions, our work with graduate students, and our work on behalf of different professional organizations. It was an easy conversation that gave us a moment to reflect on the work we had done and the work we planned to conclude in the upcoming years.

We talked about compilations of research that could guide the field, leading us to the topic of handbooks. Both Pat and I have always appreciated handbooks for teacher educators. Clandinin and Husu's (2017) *Handbook of Research on Teacher Education* and Loughran and Hamilton's (2016) *International Handbook of Teacher Education* were two that we found useful in our own work. These handbooks reviewed established and emerging research in teacher education in general, yet they offered insights to the field of science teacher education.

We found that the unique qualities, attributes, and challenges in science teacher education could intersect with the topics in these handbooks. However, the time seemed right for a handbook focused on science teacher education. We understood the potential and the need for such a handbook. Excited in our vision, within two days we had an outline for a *Handbook of Research on Science Teacher Education* and the name of a person at Taylor and Francis.

Our plan for the *Handbook* clipped along. We wanted it to capture essential areas in the field, as well as new areas in need of review. Established science teacher educators with a solid understanding of the field and emerging science teacher education researchers with fresh ideas would be the authors. We envisioned chapters that were concise reviews and that would suggest future research which would be important in years to come. Most importantly, we wanted the *Handbook* to have global appeal. We would ask authors to partner with their colleagues in different countries and attend to research across the globe. It was a lofty vision.

As the *Handbook* started to take shape, Pat was asked to take on new responsibilities at her institution. The university needed her administrative expertise. Pat felt the *Handbook* was in a good position, but she would not have the time needed to review and shape the chapters. It was a difficult decision for Pat, and I wanted to be supportive. I agreed to continue moving the *Handbook* forward, while Pat focused on a new role at her university. This was ultimately a good decision for Pat. During the writing and editing of the *Handbook*, Pat was diagnosed with an aggressive form of lymphoma, underwent chemotherapy, and recovered from a stem cell transplant. Pat reminds me often that she is forever grateful for the power of science and science education. I am too.

Pat and I discussed potential co-editors, and we agreed that Gail Jones's experience in publishing would be a tremendous asset to this project. In just a few days, Gail and I were talking about the *Handbook*. Gail needed time to think about joining the project. The workload, the reading, and the necessary comments on chapters would add to her already busy schedule. Needless to say, Gail joined the project because it sounded novel and brought her back to her passion of science teacher education.

Taking on this project was a huge leap of faith for Gail. While Pat had contributed to the conceptualization of the project, the procedural part would now rest with Gail and me. We had never worked on a project together before, but Gail's experience as an editor would be an ongoing asset. She could see how to move the chapters along and point out ways to make the chapters stronger. She was ultimately the perfect person for this stage of the project. It was clear Gail and I were like the experimentalists on a physics experiment – charged with enacting the vision of the theorists. We were constantly figuring out how to enhance the chapters in ways that could best present the field of science teacher education.

One of our first tasks was meeting with our global advisory team and our section editors. These two groups had different purposes on this project. Our intent was to make the *Handbook* global. Thus, we convened a global advisory team who suggested authors and occasionally provided reviews of the different chapters. The section editors were important in doing first- or second-level reviews that could guide the authors. In preparing for these meetings, Gail and I identified different documents that needed to be created and shared with the advisory team and editors. Gail's documents were usually completed before mine and always stated what was needed in the final product.

In working with Gail, I have learned that she is organized and procedural. We were a good team for this part of the project. We divided the chapters for review, worked with section editors, discussed the different chapters repeatedly, and decided how to bolster the ideas that were being advanced. Our Tuesday afternoon meetings were good discussions about the topics in the *Handbook*, and they resulted in suggestions that could guide the chapter authors.

As Gail and I worked with the chapters, we were always aware of the challenges our authors were facing. COVID had moved many of our authors to home offices, and many of our authors were navigating the virtual working environment. We had to strike a balance between what we could ask for and what was reasonable to request. Gail was exceptional in this area. She could see good ways to move the different chapters forward, and she could help find new authors when an author or team had to drop out.

In looking over the *Handbook*, I can see that we have achieved a global document that summarizes the research in the field. Across the 35 chapters, the *Handbook* has 111 authors, who come from 22 countries. Most of the authors are from the United States, with a good number from Chile. Authors from South Africa, Israel, Canada, and Australia also have a good presence in the *Handbook*. There are authors from Argentina, Austria, Belgium, China, Colombia, England, Georgia, Germany, Hong Kong, Luxembourg, New Zealand, Singapore, Spain, Switzerland, Taiwan, and Turkey, as well.

As this project comes to fruition, I have a few thoughts. First, I hope the *Handbook* continues to remind us that teachers are not our subjects, but partners in our research work. Each day I spend in a science classroom, I learn something new, and I realize the tremendous knowledge that science teachers hold.

Second, I hope the *Handbook* sees a second edition. I learned quite a bit during this project. Most importantly, I learned that many more areas worth examination are not included in the *Handbook*. So much more empirical work is available to be shared to guide science teacher education.

Finally, we are truly a community of science teacher educators. The individuals comprising the chapter authors in the *Handbook* include people who are new to the field and who will guide our future. Some authors are experienced science teacher education researchers who have made significant contributions over time and who have something to say. These individuals reside across the globe, and they easily associate with one another. These authors came together to create an intergenerational and globally oriented *Handbook* that will guide many educators and researchers in the field.

– Julie A. Luft, Distinguished Research Professor,
Athletic Association Professor of Mathematics and
Science Education, University of Georgia

ACKNOWLEDGMENTS

The list consists of many people who have supported and contributed to this project. To begin with, this project would not have happened without the team at Routledge/Taylor and Francis. Simon Jacobs saw the importance of this project from the beginning. As the COVID pandemic became more pronounced, Simon was still optimistic that we could manage the *Handbook*. As the *Handbook* started to take shape, AnnaMary Goodall was vital. She answered every question asked about formatting and the submission process.

Three University of Georgia students also joined the project. Kayla Prichard, who graduated with her doctorate after we started the project, and José Manuel Pavez, a doctoral candidate, willingly offered to help with the project in the beginning. They were a perfect team in the early part of the project. As time went on, José shifted to a more central role in the project. Joe DeLuca joined José in preparing the final document for Taylor and Francis. Their attention to detail was essential during this phase. I am forever indebted to José for his connections to collaborators across the globe (many in the *Handbook*) and for his attention to detail in organizing the *Handbook* for submission to Taylor and Francis. The *Handbook* would not be possible without Kayla, José, and Joe.

The *Handbook* came into its own because of the section editors. The team was great to work with from the beginning through to the final stages. Each section editor was diligent in communicating with authors and focused on having each chapter in its best state. As in all endeavors, these editors brought their own skills to this project. It was an outstanding team. Thank you, Sarah J. Carrier, Lauren Madden, David F. Jackson, Soonhye Park, and Rachel Mamlok-Naaman.

Finally, this project was made possible, in part, through funding from the University of Georgia Office of the Vice President for Research and the Athletic Association Professorship in Mathematics and Science Education. The findings or conclusions offered in the *Handbook* do not necessarily reflect the views of the people at these organizations.

SECTION 1

Research in Science Teacher Education

Section Editor: Julie A. Luft

Science teacher education relies on empirical work to advance the field. Through investigations of science teaching, science learning, and teacher learning, knowledge accumulates that provides insights into ways science teachers should be supported throughout their careers. Investigations in the field of science teacher education can use different theories, methodologies, or methods to contribute to the knowledge base. Of course, the methodological, theoretical, and conceptual orientation also entails a sound understanding of the studied area. As many researchers know, these considerations are only a few that are important for empirical work that contributes to the field.

The chapters in this section represent a few areas associated with empirical work in science teacher education. They were initially envisioned to be educative and directive for those in science teacher education and science teacher education research. With a broad charge, the authors of these chapters offer science teacher education researchers insights into different dimensions of educational research. They conceptualize science teacher education research, contemplate methodological approaches, and illustrate how a theoretical orientation can contribute to the field of science teacher education.

This section begins with a chapter by Erduran and Guilfoyle, who take a broad view of the nature of research in science teacher education. In their conceptualization of the research, they describe the space existing between science teachers and science teacher educators. The complex nature of this research space is evident in the examples they provide. They describe a continuum of teacher learning that reaches from preservice teachers to experienced teachers to knowledgeable veterans. Science teacher educators engage in the process of research in different ways. These groups are essential in shaping the space of science teacher education research.

Erduran and Guilfoyle's chapter is to be appreciated for the way in which they attempt to portray this space. Like a painting that is the result of both subject and artist, the activity of science teacher education research is varied. Within this activity is a topic of study that associates with an area and that can have an orientation that ranges from broad, macro, or general to refined, micro, or specific. The varied positioning becomes evident in the examples later in the chapter. However, Erduran and Guilfoyle leave the door open for different configurations or descriptions that comprise the activity of science teacher education, and future science teacher educators are left to contemplate these configurations.

Within science teacher education research are different methodologies and methods that contribute to the variability of contributions. The next chapters broadly contemplate these areas. Tai, Taylor, Reddy, and Banilower provide an overview regarding large data sets that are used in education. The data sets they focus on are the Trends in International Mathematics and Science Surveys (TIMSS), the National Teachers and Principals Survey, the National Assessment of Education Progress, the National Survey of Science and Mathematics Education, and the High School Longitudinal Study of 2009. In their examination of these data sets, they suggest how the data can be used to inform science teacher education and add to the field's knowledge in various science teacher education research areas.

Their overview provides science teacher educators and researchers with some important considerations related to using these data sets. As experienced researchers who work with large data sets, Tai et al. are the right people to distill the important considerations that should be made when working with these and similar data sets. They also provide a solid example from South Africa about how an analysis of TIMSS data can guide science teacher educators in their work with teachers.

Moore Mensah and Chen, in contrast to analyzing large data sets, explore how science teacher education researchers utilize qualitative or interpretivist research methods. Their analysis of published articles reveals that general qualitative studies and case studies were the most prevalent methods, followed by grounded theory, ethnography, phenomenology, narrative, action research, and self-study. To frame these areas, spotlight studies are selected and described in a way that provides insights about these types of studies to both new and experienced researchers.

The descriptions provided by Moore Mensah and Chen illustrate the manner in which these studies are designed and enacted. These descriptions also provide guidance to those who engage in qualitative research. The authors point out the complex nature of qualitative work and the importance of qualitative research in understanding the varied nature of science teacher education. They also reiterate the need for the purposeful selection and discussion of the research process, especially in areas needing understanding. Qualitative research, they posit, is well-positioned to explore and address many topics that are underexplored – most notably, issues of power/knowledge, diversity, equity, and inclusion.

Buck and Williamson's chapter on mixed methods research is focused on ways mixed methods studies can and do contribute to the knowledge base in science teacher education. They begin their overview by defining mixed methods research, which is followed by a discussion of the purposes and questions associated with mixed methods research. The rest of the chapter describes the ways mixed methods approaches are used in science teacher education, what has been learned from mixed methods work, and what mixed methods researchers should look toward in the future.

The important contribution of this chapter resides in two areas: the discussion of ways mixed methods research is used in the science teacher education community and the knowledge obtained through mixed methods approaches. Not surprisingly, much of the mixed methods research in science teacher education is evaluative in nature. Buck and Williamson suggest that science teacher education researchers should move beyond this evaluative stance and use mixed methods approaches to understand the more nuanced how-and-why aspect of a study. This methodological orientation will help build a knowledge base with utility in science teacher education.

The final chapter in this section, by Calabrese-Barton, Tan, Schenkel, and Benavides, focuses on the equity-oriented research framework referred to as "rightful presence." According to Calabrese-Barton et al., this emerging framework pushes equity beyond the notions of inclusion and focuses on high-quality learning experiences that allow students to address their experiences and redress systemic inequities. In this section, they describe the framework, link it to science teacher education, and suggest ways science educators and science teachers can support the enactment of this framework.

The contribution of the chapter to this section is significant. It illustrates how an emerging framework focused on students can be used to guide research in science teacher education. Descriptions in this chapter are drawn from their work in the field with teachers, and they suggest how teachers can create this type of instructional space. The focus on the enactment of a rightful presence framework certainly leaves room for research that explores how science teachers move (or not) toward this approach. The space between the framework and the actions of the teachers and students is ripe for exploring how to support science teacher learning. This opportunity for research occurs with so many other frameworks that are important in science teacher education.

As a collection, the chapters in this section provide a characterization of science teacher education research, an overview of a few research approaches, and an example of ways in which a framework can guide research and implications for science teaching. While several other chapters could have been included in this section, these chapters serve as a beginning point. As researchers review these chapters, they may engage in generative discussions that contemplate how science teacher education researchers engage in their investigations, how they situate their work within a framework, and how their work contributes to the knowledge base in the field of science teacher education. We hope these discussions result in new characterizations, overviews, or examples, and potential chapters for the next handbook.

1

THE IMPORTANCE OF RESEARCH IN SCIENCE TEACHER EDUCATION

Sibel Erduran and Liam Guilfoyle

Introduction

Research in STE is a complex area that involves a range of theoretical perspectives (e.g., sociocultural theories, cognitive psychological frameworks), methodological approaches (e.g., action research, experimental studies, ethnographies, case studies) and actors (e.g., teacher educators, student teachers, in-service teachers). Not all research is STE is empirical in nature. In fact, very important research involves conceptual, theoretical, philosophical, or other non-empirical approaches. For example, there are systematic reviews (e.g., Rushton & Reiss, 2021) and meta-analyses on STE (Kraft et al., 2018). Often, theoretical studies challenge the community to think about what key issues need to be the focus of investigation, problematizing the function, purpose, or direction of STE in research, policy, and practice (e.g., Luehmann, 2007). In this chapter, we trace the scope and breadth of recent research in STE by raising three questions: (a) What are the purposes of research in STE? (b) What are the key concepts and methods underpinning research in STE? and (c) What are some example areas of research in STE? Given that STE is a very rich and complex domain as evidenced by the remit of this handbook itself, it is beyond the scope of a single chapter to cover all aspects of research in STE. Hence, the chapter is intended to provide a meta-perspective on a set of example areas of research to illustrate the rationale for carrying out research in STE and to illustrate some indicative areas of work for advancing the field.

Many international curriculum reform efforts have placed new and emerging demands on science teachers, making it necessary to develop teachers' knowledge about a whole range of issues (Reiser, 2013). For example, in the USA, the Next Generation Science Standards (NGSS) (NGSS, Lead States, 2013) have recently prompted a shift in the emphasis away from the breadth of too much content to a focus on the in-depth development of core explanatory ideas. Similar shifts in curricula in other parts of the world have been observed, for instance in the case of the inclusion of argumentation in the science curriculum in South Africa (Erduran & Msimanga, 2014). Another dimension of recent science curriculum reform includes the emphasis on integrated science, technology, engineering, and mathematics (STEM) in education when, traditionally, these subjects are taught separately in schools. However, research has illustrated that there may be a lack of coherence in how different aspects of STEM are represented in curriculum documents. For example, by tracing the disciplinary aims, values, methods, and practices of STEM disciplines in science curriculum standards from Korea and Taiwan as well as the USA, Park et al. (2020) demonstrated that mathematics is underemphasized in science curriculum statements.

DOI: 10.4324/9781003098478-2

In light of recent developments in science curriculum reform, we review a set of themes that highlight the significance of research in STE. Researching the experiences of teachers as they navigate their developmental journey is helpful for teacher educators to better understand so that they can respond to teachers' needs. Likewise, teacher educators' research into their own practice can potentially improve the quality of their teaching. The discussion will identify (a) the purposes of doing research in STE, (b) the key constructs that frame research in STE, and (c) some example areas of research in STE. As we survey research in STE, we will often use the generic term "teacher" rather than the specific terms preservice teacher (PST) or in-service teacher. This is in recognition of the continuum of teacher education, which extends beyond the initial phase focusing on preservice teachers (Kahle & Kronebusch, 2003).

Key Constructs in Research in Science Teacher Education

Teacher education can be highly contested and variable in different jurisdictions around the world (Kitchen & Petrarca, 2016). Over the past decade, there have been increasing calls for teacher education to become more "evidence informed" and for research to become a more integral part of teacher education (Menter & Flores, 2020). The role of research in teacher education programmes was discussed in broad and inclusive terms by the BERA-RSA report (2014). The report cited purposes such as (a) informing the content of teacher education, (b) informing the designing and structure of teacher education, (c) equipping teachers and teacher educators to engage with and be discerning consumers of research, and (d) to equip teachers and teacher educators to conduct their own research investigating the impact of particular interventions or to explore the positive and negative effects of educational practice. It has also been argued that teacher educators' understandings and experiences of research can influence their teaching approaches in initial teacher education (Brew & Saunders, 2020). Therefore, it appears important to develop research programmes in teacher education where teacher educators investigate their own practices and "engage in collaborative research-based partnerships with school mentors, student teachers and teachers" (Menter & Flores, 2020, p. 9).

As a research field, STE literature presents a plethora of theoretical and empirically derived constructs such as "Pedagogical Content Knowledge" (PCK) and "Metacognition" which are also prominent in generic teacher education literature. These constructs often frame researchers' discussions about how teachers learn to teach as well as the nature of their pedagogical and subject knowledge. Numerous theoretical orientations, thus, inform such constructs including cognitive psychological accounts in the case of "metacognition" and epistemological perspectives, including the nature of subject knowledge (Schwab, 1962). PCK, a concept proposed by Lee Shulman (1986), has framed much research in STE. PCK has provided a powerful framework to illustrate a central feature of teachers' knowledge. Shulman described PCK as "The most useful forms of content representation . . . the most powerful analogies, illustrations, examples, explanations, and demonstrations – in a word, the ways of representing and formulating the subject that makes it comprehensible for others" (p. 9). Various iterations of PCK have been proposed by other researchers, often complemented with other aspects of science teaching including subject knowledge (Berry et al., 2015; Hume et al., 2019).

Grossman (1990) added two other components to Shulman's original PCK components: knowledge of curriculum, and knowledge of purposes for teaching. A further account was proposed by Magnusson et al. (1999). This model added three components to Shulman's original ones: orientation to teaching science (i.e., knowledge and beliefs about purposes and goals for teaching), knowledge of science curricula, and knowledge of assessment of scientific literacy. A recent perspective on teacher knowledge uses a transformative yet structured model of teacher professional knowledge and skills. A model proposed by Gess-Newsom (2015) incorporates ideas from Shulman (1986), such as PCK, as well as other concepts such as Teacher Professional Knowledge Bases (TPKB) and Topic Specific Professional Knowledge (TSPK). The model makes explicit that content for teaching occurs at the topic levels (i.e., chromatography) and not at the disciplinary level (e.g., chemistry). Furthermore, authors have argued that subject matter, pedagogy, and context can be considered in unison.

"Metacognition" is another widely and broadly used concept in teacher education. It is often considered as knowledge about cognition which refers to one's knowledge about her/his own cognition (Schraw & Moshman, 1995). It consists of three sub-components: (a) declarative, (b) procedural, and (c) conditional knowledge. Declarative knowledge is defined as one's knowledge about oneself as a cognitive processor. Procedural knowledge involves knowledge about execution of procedures for a specific cognitive task. The conditional knowledge refers to knowledge of why and when to use a particular strategy for a particular cognitive task. Accounts of science teachers' cognition include domain-specific aspects of science teaching, such as the teaching of scientific inquiry. Examples of metacognition articulated in the work of STE researchers include Zohar's (2012) framework that distinguishes meta-strategic knowledge or MSK as a sub-component of metacognition. MSK is the "thinking behind the thinking" (meta-level of thinking) rather than the "thinking behind the doing" (Zohar & Ben-David, 2008).

Research in STE is conducted through a range of methodological approaches. The sorts of knowledge claims that these audiences are interested in may differ, and so the sorts of evidence or method of generating evidence that they value may also differ. More generally, there are noticeable trends towards valuing forms of evidence in education, and efforts to make educational research "more scientific" (Wrigley, 2018). Researchers in STE often use experimental methods and randomised control trial (RCT) approaches to study the impact of interventions. While there is perhaps a heightened value on RCTs or experimental studies in some spheres, researchers in STE recognise value in wider forms of evidence for informing practice. There are a broad range of frequently used research approaches beyond the experimental designs, including action research, ethnographies, and case studies. Quantitative (Ronald, 2012) and mixed methods (Luft et al., 2011) studies that seek to explore and explain relationships between variables, such as between teacher competence, quality, and student outcomes (e.g., Fauth et al., 2019). Further examples include investigations about how individuals in particular contexts respond in given research instruments for beliefs or understanding at points in time, or developmentally over periods of time (e.g., Herman & Clough, 2016).

Areas of Research in Science Teacher Education

Research in STE often differentiates the issues related to beginning and in-service teachers (Cochran et al., 1993; Friedrichsen et al., 2010). The needs of beginning and experienced teachers can vary significantly. For example, while experienced teachers can benefit from professional development on higher-order thinking skills, novice teachers tend to focus on more basic matters such as classroom management (Luft et al., 2011). Regardless of the career trajectories of teachers, studies on teacher education draw from a range of foundational disciplines that frame science teaching and teacher education. Some areas are guided by theoretical constructs from diverse fields such as cognitive psychology – for instance, those focusing on teachers' cognition (Borko & Putnam, 1996) – and sociology of the teaching profession – for instance, those focusing on teaching in the broader societal norms and institutional imperatives (Ferfolja et al., 2015). Figure 1.1 provides an illustration of the areas of research in STE and the ways in which these areas relate to each other.

Any such illustration will necessarily be limited insofar as it is a reduction of the true complexity of teacher education. However, such representations can help summarise some of the key constituents of teacher education where research efforts are placed. In the center of Figure 1.1 lies the activity of STE. This activity is flanked by the primary actors involved in the activity, namely teachers and teacher educators. Research in STE will be related to all three of these elements, but some research is associated with one more than the others. A wide range of research is undertaken pertaining to the actors involved in teacher education (i.e., their beliefs, their background profiles and journeys, or

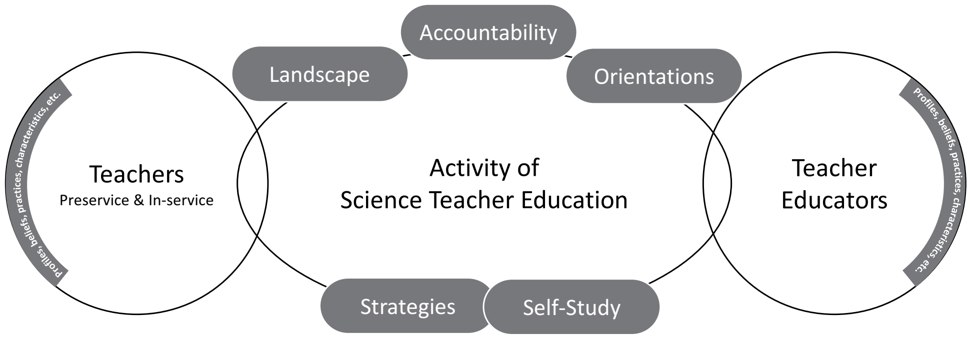

Figure 1.1 Areas of research in science teacher education

other characteristics) as well as systemic elements including the broader policy landscape of teacher education and accountability measures.

There are a variety of different areas and levels of research on the activity of STE, and some of the most pertinent of these are represented around the outside of the activity. Many of these are unpacked in greater detail in the body of the chapter but are briefly introduced here as a way to think about the breath of research in STE. *Landscape* refers to the kinds of research that are most concerned with understanding the "current state" of STE, particularly in light of policies in national as well as international comparative contexts (Scherr & Chasteen, 2020). For example, research can focus on who is entering STE (Roloff Henoch et al., 2015) or the policies relating to STE more generally (Olson et al., 2015). *Orientations* refers to the forms of research which are related to the overarching principles of STE, often informed by philosophies of education or other underpinning values. These principles and values guide the decision-making of STE and even the fundamental structure or approach to teacher preparation that is adopted (Craig, 2016). *Accountability* as a term in this representation includes a reasonably wide range of research interests. It differs from *Landscape* in that it is less about providing an account of the current state (the who, what, and how of current provision) and more about the measures and outcomes of the process.

The most familiar area of research is related to how teacher education programmes are evaluated for their outcomes such as teacher retention (Zhang & Zeller, 2016) or student achievement (Boyd et al., 2009). Subsumed in such evaluations, there is also the assessment and certification of teachers that many teacher education providers are accredited to undertake (Richmond et al., 2019). An area of research involves teacher competencies and how to assess that such competencies are adequately developed in STE. *Strategies and self-study* are closely related in that they can both be concerned with the practices of teacher educators (Bullock & Russell, 2012; Hordvik et al., 2020; Loughran et al., 2004). Research on pedagogical strategies used in STE can be subjected to a wide range of forms of empirical study, some of which are on a large scale (Ronald, 2012) while others are investigated and usefully described in rich detail through an individual teacher educators' own self-study (Russell & Berry, 2014). Teacher self-studies can be concerned with their own developmental journeys as actors in the activity of teacher education, and not just about the impact of their strategies. In the rest of this section, we focus on some example areas of research that are subsumed under each aspect of the broad characterisation in Figure 1.1.

Teacher beliefs, attitudes, dispositions, and identities

Research on beliefs, attitudes, and dispositions of teachers, both preservice and in-service, has been a long-standing strand in STE (Bryan, 2012). Much of this research has been motivated by the need to identify the thought processes that drive teacher behavior, paralleled with the idea that changes in such mental constructs could yield changes in teaching practices (Cochrane-Smith & Fries, 2005). Approaches in research shifted towards considering teacher education as learning experience where it was necessary to understand how teachers' knowledge and beliefs develop, and how teachers ultimately translate these beliefs into practice (Bryan, 2012). The task of defining the construct of teacher beliefs is a challenging one (Pajares, 1992), and despite a growing literature on the topic, it continues to be "murky" and lacking consensus (Fives & Buehl, 2012). Nonetheless, it has been argued that preservice teachers come to teacher education with pre-existing beliefs (Yesil-Dagli et al., 2012) and these beliefs act as filters for the information encountered in their education (Fives & Buehl, 2017). It is therefore important for teacher educators to investigate and understand the beliefs of preservice teachers to establish how their learning progression can be supported (Guilfoyle et al., 2020).

A range of beliefs, attitudes, and dispositions have been examined as important and influential in teacher education, including instructional beliefs (Rubie-Davies, 2015), goal-orientation beliefs (Anderman et al., 2002), self-efficacy beliefs (Cakiroglu et al., 2012), as well as beliefs about assessment (Barnes et al., 2015), technology (Hermans et al., 2008) and diversity (Gay, 2010). Among the wide range of beliefs that are relevant for teaching in general, beliefs about the nature of the subject/discipline are clearly of particular importance to STE. Shulman (1986) argued that teachers need to be able to guide students not only in learning the "accepted truths in a domain" but also in why these truths are deemed warranted in the domain (p. 9). For science teachers to be able to do so, STE must consider understanding of the nature of the discipline as part of the subject matter preparation of teachers (Ball & McDiarmid, 1990). Indeed, the science education community has long focused on this issue of students' and teachers' beliefs about the nature of science (e.g., Erduran & Dagher, 2014; Lederman, 1992).

Some researchers have taken particular interest in the beliefs about the epistemic nature of the discipline and considered how these play a role in learning (Peng & Fitzgerald, 2006), teaching (Kang, 2008), and learning to teach (Buehl & Fives, 2016). Researchers are often interested in how such themes develop over time. Consequently, longitudinal studies have been designed and implemented to trace teachers' development over the course of teacher education and into their careers (Buldur, 2017; Herman & Clough, 2016). A relatively recent area of research in STE focuses on science teachers' identities (Avraamidou, 2014), and here, too, there is growing interest in identity development through the life cycle of the teacher (Hong et al., 2017). Although this is a recent emphasis in science education research, preservice science teachers' identities have been investigated from a developmental and social psychological perspective in the broader teacher education for a number of years (Friesen & Besley, 2013).

Pedagogy of Teacher Education

Being concerned with the development of teachers, STE researchers take particular interest in understanding the aspects and activities of teacher education that can support teachers' professional development. Studies of the content and processes of teacher education take a number of forms. At the broadest level, studies can be conducted which aim to generate an understanding of the landscape of STE provision at any given point in time. For example, the Research on Science Education Survey (ROSES) report in the USA (Newton & Watson, 1968), provided insight into, amongst other things, the particular practices of teacher education employed in various institutions (e.g., the use of class discussion, student laboratories, student demonstrations, mock teaching, construction of teaching units, and lecturing). Other studies about the pedagogy of STE can focus on the level of the overarching orientation to programme construction. More recently, Olson (2017) explained how STE programmes can be differently constructed depending on the conceptual orientation of "construction," "resolution," "discrimination," or "assimilation."

Korthagen (2016) argued that the pedagogy of teacher education should be different from other areas of higher education and that teacher educators need to "show exemplary pedagogical behaviour" (p. 313). Thus, the development and study of specific pedagogical practices in teacher education has been an important and growing area of research. Korthagen reviews illustrative examples of specific pedagogical practices and techniques that have been studied in the context of teacher education, including workplace learning, case methods, the use of video, approximations of practice, reflective practice, learning communities, narratives, teacher research, portfolios, and modeling (2016, pp. 320–331). In the specific case of STE, Berry and Loughran (2012) documented how science teacher educators developed their personal pedagogies for STE, and how they articulate these pedagogies in ways that can impact the work of others. They describe a series of self-studies where science teacher educators explore tensions in their practice to build upon and communicate their pedagogies. However, science teacher educators can investigate pedagogies in other ways as well. For example, Scantlebury et al. (2008) conducted a longitudinal ethnographic study of the implementation of co-teaching in an undergraduate science education course. In doing so, they evaluate their own practice and share both the affordances and challenges of the pedagogical strategy for preservice teachers and teacher educators.

Siry and Martin (2014) used case study approaches to examine the role of video analysis in supporting preservice science teachers to reflect on their classroom teacher, in tandem with cogenerative dialogue, to make reflexive changes to their practice. They argue that while the pedagogy of using video-based media in STE has received attention in literature, there is less reporting of the impact resulting from such practices for teachers. Siry and Martin's research suggests that their dialogic video analysis can be transformative for preservice teachers' practice. Hetherington and Wegerif (2018) use a large-scale international teacher survey and teacher interviews in a case study school to argue how dialogic pedagogy in STE needs to be cognisant of the material-dialogic relationships (i.e., not just focusing on words, but also how material resources used in the science classroom are linked to the dialogue). In this case, the research advocates for a pedagogy of teacher education by identifying a gap, rather than evaluating the implementation of the pedagogy. In summary, the scope of research on the pedagogy of STE is vast and diverse, ranging from the macro levels of ascertaining the landscape of provision and categorisation of approaches to programme construction, to micro levels of measuring and articulating pedagogical strategies.

Teacher Educators' Professional Development

An important yet still growing focus of research in teacher education has been on teacher educators themselves, including their journeys, identities, beliefs, practices, and competencies (Korthagen et al., 2005; Lunenberg et al., 2011). However, there is still much left to do in this area, particularly in the specific cases of science teacher educators (Berry & Van Driel, 2012). Research studies on teacher educators address the questions of "Who teaches teachers?" "How do they become teacher educators?" "How can teacher educators be supported in their development?" These studies can focus on the personal experiences and professional journeys to becoming a teacher educator, including the challenges and opportunities along the way. Some focus on pathways through various career roles, such as from classroom teacher to cooperating teacher or from school-based mentor to university teacher educator (e.g., Zeichner, 2005). Others focus on the implications of the academic expectations of teacher educators, whose identities and backgrounds do not always match the "academic scholar" of other disciplines in the academy (e.g., Murray & Male, 2005; Loughran, 2011). Such research on teacher educators can help to better understand how STE works in practice and how best to support science teacher educators' own professional journeys.

An example of a study that homed in on the case of subject discipline teacher educators is that of Johnston and Purcell (2020). These authors explored the profiles and practices of those involved in initial teacher education programmes who provide disciplinary content knowledge to preservice teachers (e.g., a physics lecturer on a teacher education course). Johnston and Purcell argued that although undergraduate preservice teachers would spend a significant portion of their initial teacher education course with such subject discipline teacher educators, little attention has been paid to them in teacher education research or policy. Erduran and Kaya (2019) reflected on their own journeys as science teacher educators as they collaboratively designed and taught a preservice science teacher education course about nature of science. The authors remarked about their own exposure to the foundational disciplines of history, philosophy, and sociology of science that help frame nature of science in science education. Research accounts of science teacher educators thus help to identify the opportunities as well as constraints to teacher educators' own knowledge base in what they are including in their teaching. Berry & Van Driel (2012), in their study of science teacher educators' expertise and practices, suggest that this form of research can contribute not only to a better understanding of science teacher educators' work but also to "the development of a pedagogy of STE" (p. 117).

Teacher Education Communities, Institutions, and Accountability

Some researchers argue that a systemic approach that considers teacher education communities, institutions, and accountability mechanisms is necessary for significant and lasting changes to reforming science teacher education (Bryk et al., 2015; Coburn & Penuel, 2016). However, research investigating STE through frameworks focusing on a systems approach are scarce. Based on a review of literature, Allen and Heredia (2021) specify four practices that can aid in designing professional learning to facilitate science teachers' organizational sensemaking of science reform. These practices are intended to complement and expand upon existing best practices for teacher professional learning, including active learning opportunities for teachers. The authors recommend practices that are aimed at intentionally surfacing organizational sensemaking: (a) anticipating sources of uncertainty and ambiguity teachers may experience due to their organizational context and (b) triggering sensemaking during professional learning meetings. These practices are then followed by opportunities to reduce ambiguity and uncertainty through (c) collective meaning-making and materials development and (d) sustained professional development and iteration around perceived barriers to implementation.

Organisations that provide teacher education are governed by accountability for quality and performance (Gitomer, 2003). For example, in many parts of the world, there are government-based standards for being qualified to teach, and teacher training programmes are periodically inspected for quality assurance purposes. Research on such matters of accountability is often conducted within organisational settings and commissioned by the relevant organisation. For instance, in the United Kingdom, Ofsted has published research evidence underpinning the education inspection framework. Ofsted stands for Office for Standards in Education, Children's Services and Skills, and it is a non-ministerial department of the UK government, reporting to Parliament. Ofsted is responsible for inspecting a range of educational institutions, including initial teacher training. Ofsted regularly conducts research drawing on a range of sources, including both Ofsted's own research programme and a review of the existing evidence base. Ofsted subsequently used their research report to justify the key judgements for a proposed new framework on inspection of schools, including quality of education, leadership, and management (Ofsted, 2019). When research is conducted within the institutional settings of accountability, particular biases may potentially arise guided by ideological stances (e.g., Murray & Wittaker, 2018). Nevertheless, it can also be argued that the research-policy gap is narrowed when organisations that govern and lead STE provisions engage in research.

Discussion and Conclusion

The chapter outlined an overview of research in STE, including some key constructs and areas of research. The discussion raises numerous questions, some of which pertain to long-standing problems. For example, questions about the theory-practice gap (Kortkagen & Kessels, 1999) and scaling up of research outcomes involving a small number of teachers to the system level of teacher education (Schalock et al., 2006) persist. As the research base in STE continues to build, a significant concern is the extent to which congruence in evidence is established across the various methods, agents, concepts, and contexts of research. At times, the interpretations in evidence may potentially include biases of researchers imposing meanings on teachers, teaching, and teacher education not necessarily matching those of the participants of research. Convergence in collaboration and dialogue among the stakeholders of STE is likely to improve the credibility of evidence generated through multiplicity of approaches to research in STE. Some examples of spaces that are aiming to create platforms for such interaction are beginning to emerge. For instance, there are now websites that build connections, mediate the development of research projects, and enable sharing of research findings as exemplified by the *Teachers' Research Exchange (T-Rex)* in Ireland (McGann et al., 2020). Such initiatives are already extending the more traditional School-University Partnerships for research collaboration in STE, such as the Oxford Deanery situated at our own institution (Fancourt et al., 2015) and research briefs generated by organisations such as the NSTA in the USA that are intended to communicate outcomes of research. Ultimately, effective incorporation of robust research evidence in STE will ensure that science teachers are well prepared for the demands of teaching.

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Professional Identity as a Framework for Science Teacher Education and Professional Development

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