Contributions from Science Education Research 9

Olivia Levrini · Giulia Tasquier
Tamer G. Amin · Laura Branchetti
Mariana Levin *Editors*

Engaging with Contemporary Challenges through Science Education Research

Selected papers from the ESERA 2019 Conference

Springer

Contributions from Science Education Research

Volume 9

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In memory of Nella (Lella) Grimellini Tomasini.

Nella (Lella) Grimellini Tomasini passed away on March 27, 2020.

We wish to dedicate this book to her.

Lella founded the research group in Physics Education in Bologna in the 1960s and took an active part in the establishment of ESERA in Leeds, 1995. We decided to organize the ESERA conference in Bologna mainly because of her special feelings of affection toward ESERA.

She made original contributions in research on conceptual change, teacher education, and the role of the laboratory in the teaching and learning of physics as a culture.

We all remember her for her lively and brilliant intelligence, her iron determination and attention to detail, her elegant passion for knowledge, and for "the pleasure of understanding." Her special way of "looking at science to see human thought reflected in it" is etched into how we continue to carry out our research and nurture our intellectual and human collaborations.

We will miss her.

Introduction

This edited volume is composed of selected papers that were presented at the 13th European Science Education Research Association (ESERA) Conference, held in Bologna, Italy, from the 26th to the 30th of August 2019. The ESERA 2019 Conference theme was ***The beauty and pleasure of understanding: Engaging with contemporary challenges through science education***.

The organization of the ESERA 2019 conference was undertaken by Olivia Levrini (Conference President) and Giulia Tasquier (Conference Manager) in collaboration with the research group in Physics Education and History of Physics at ALMA MATER STUDIORUM – University of Bologna, and with the support of the Steering Committee, the Local Organising Committee, the Scientific Committee and the ESERA Executive Board. Technical and logistical support was provided by EGA Worldwide.

ESERA is an international organization for science education researchers and science educators, and it aims to: (i) enhance the range and quality of research and research training in science education; (ii) provide a forum for collaboration in science education research; (iii) represent the professional interests of science education researchers in Europe; (iv) seek to relate research to the policy and practice of science education in Europe; and (v) foster links between science education researchers in Europe and elsewhere in the world (www.esera.org).

The ESERA community consists of professionals with diverse disciplinary backgrounds, ranging from the natural to the social sciences. Such diversity provides a broad range of perspectives on research, practice and policy in science education and is well reflected in this volume. The biennial ESERA conference is the main forum for direct scientific discourse within the community, for exchange of insightful practices, and for extending networks among researchers and educators. The contributions in this volume showcase current orientations of research in science education.

Overall, this book will be of interest to an international audience of science teachers, teacher educators and science education researchers who have a commitment to evidence-based and innovative science teaching and learning.

Behind the Scientific Organization of the ESERA 2019 Conference

As we worked to create the scientific program of the conference, we (the Scientific Committee for ESERA 2019) tried to imagine the story that we hoped would emerge from the dynamics of the conference – that would be "in the air" and would stimulate formal and informal discussions among attendees. The story that emerged was pre-pandemic, but already it was strongly influenced by dramatic changes that were occurring in our respective societies. We were (and continue to be) living in what the sociologist Hartmut Rosa calls "the society of acceleration" (Rosa 2013), a society accelerated by the impressive velocity of scientific and technological (S&T) development. And we were, and are, living in a moment of deep social, political, and environmental global change, exacerbated by the COVID-19 crisis.

Many demanding contemporary challenges, that involve science education, deeply affect the present and the future of the younger generation and of the planet: climate change, multiculturalism, the flourishing of new interdisciplinary domains (like cognitive neuroscience, artificial intelligence, digital humanities to name a few), as well as issues stemming from living in the digital and post-truth era. With this backdrop, the questions that arose during the process of organizing the conference were: how can we, as researchers in science education, contribute to equipping the younger generation with what they need to cope with contemporary challenges like these? In particular, what contribution can a conference like this one make?

In this frenetic and fast-changing society, we imagined a conference where it would be possible to take time to deeply reflect on what was happening in the present, while also taking time to push our imagination forward – to think about possible, alternative, desirable future scenarios for science education and for the relation between science and society. Specifically, to enhance these discussions, we started from the belief that, being science educators, generating understanding is for us the preferred way to address these challenges, recognizing also that these challenges are so deep and novel that addressing them via science education necessitates collectively searching for new narratives, languages and forms of beauty that capture our attention and trigger new ways of thinking.

Accordingly, we decided upon the theme of the conference, *The beauty and pleasure of understanding: engaging with contemporary challenges through science education,* and tried to create moments and contexts that would nurture a deeply reflective attitude on the present and on current science education research and, at the same time, inspire a provocative and visionary attitude toward the future.

Indeed, both the theme for the conference and the invited speakers and symposia were chosen to be "foundational" (for the purpose of orienting the community towards reflection on current science education research and practice) and/or "visionary" (able to open new, positive, and active windows towards the future). Specifically, the opening speech by Igal Galili was about "The beauty and pleasure of understanding" detailing the importance of aesthetic engagement in science education, moving beyond "understanding" in its more narrow sense, as well as pointing out the special history of the city of Bologna in debates on beauty and understanding. The first plenary lecture was given by noted Icelandic writer, Andri Snær Magnasson, who alerted us to the ways climate change challenges all our available forms of describing a phenomenon, from numerical representation to the myths of a society. This theme is engaged with in the first chapters of the book. The other three plenary talks and one panel by prominent researchers led to chapters that appear in different sections of the volume and were titled (ii) Where are we? Syntheses and Synergies in Science education research and practice (Bruce Sherin); (iv) Embodied cognition: From Neuroscience to Science Education (Corrado Sinigaglia & Tamer Amin); (v) Socioscientific-issues: Searching for new perspectives (Maria Evagorou and Jan Alexis Nielsen); (vi) Science Education in Multicultural and Multilingual Contexts (Mariona Espinet, Saouma BouJaoude, Sonya N. Martin, Audrey Msimanga and Alberto J. Rodríguez).

A total of 1792 single and multi-paper proposals were submitted to the ESERA 2019 conference in early 2019. Of the 1061 proposals submitted for single oral presentations, 824 were presented at the conference. A total of 410 proposals were presented as interactive posters and this included contributions from 91 young researchers who had attended the ESERA summer schools (in 2017, 2018, 2019). In total, of the 73 submitted, 63 symposia (each with four papers) were presented at the conference, of which 16 were invited symposia. Each symposium was organized by a coordinator around a specific topic and each of the papers addressed the topic from different perspectives by authors from different countries. Moreover, 15 sessions were presented in the format of an ICT demonstration, hands-on workshop or as a World Café. The conference week was thus richly scheduled with single oral presentations, symposia, interactive posters, ICT demonstrations and workshops divided into 18 different strands based on their topic (see www.esera2019.org).

After the conference, all presenters were invited to submit revised and extended papers on their conference presentation to the electronic proceedings of the ESERA 2019 Conference, which is available at https://www.esera.org/publications/esera-conference-proceedings/esera-2019 (Levrini, O. & Tasquier, G. (Eds.) (2020). Electronic Proceedings of the ESERA 2019 Conference. The Beauty and Pleasure of Understanding: Engaging with Contemporary Challenges through Science Education, Bologna: ALMA MATER STUDIORUM – University of Bologna. ISBN 978-88-945874-0-1).

The ESERA 2019 Conference was attended by 1609 science education researchers from 58 countries around the world and thus the conference was indeed a very international meeting. While presenting one's own research and engaging with others in discussion were among the most important aspects of the conference, having an opportunity to meet other science education researchers was just as valuable. The discussions at conference sessions provided opportunities for researchers and practitioners to exchange their experiences and approaches. The countless encounters with other researchers throughout the week enabled the participants to strengthen their existing networks, make new acquaintances and sow seeds for future cooperation.

Overview of the Organization of the Volume

This volume includes science education research presented at the ESERA 2019 conference identified by the strand chairs and the scientific committee as particularly interesting and representative of current work in the field. The topics discussed will generate interest and spark debate within the community of science education researchers and science educators. The editorial team is very grateful for all the work carried out by the international panel of strand chairs and reviewers who made it possible to include these selected papers in this compilation. Following the conference, the strand chairs recommended interesting conference contributions as possible papers for this book by following common criteria. The selection made by strand chairs was examined by the scientific committee and a selection of recommended authors were invited to submit full manuscripts. The papers underwent a rigorous scientific review process involving at least two reviewers per paper and the scientific committee. As the final product of the review process, this volume is composed of 25 chapters, organised in four sections: (1) Meeting societal challenges, (2) Expanding the evidence base, (3) Developing innovative theoretical perspectives and methodologies, and (4) Designing research-based instruction.

In the first section, we included chapters that examined how science education research could help meet contemporary societal challenges. These chapters engaged with broad policy issues, examined novel curricular approaches to meet societal concerns and reported on studies of science learning and instruction that focused on how learners could be prepared for meeting the pressing challenges of our time.

In the second section, we brought together chapters that focused on expanding the empirical base of current science education research. Any empirical field relies on its evidence base to validate its claims. The field of science education relies on evidence-based claims to ground its practical curricular and instructional recommendations. Indeed, the community of science educators is acutely aware that theoretical frameworks are complex knowledge structures that must be supported by a collective body of evidence. Thus, expanding the evidence base cumulatively via theoretically framed and methodologically rigorous investigations is crucial. This section includes chapters that report on empirical studies with clear theoretical framing and carefully designed quantitative and/or qualitative methods.

The third section is organized around a shift in focus toward the development of innovative theoretical perspectives and methodologies. To meet societal challenges that are increasingly complex, our theoretical understanding of science learning and instruction needs to match this complexity. This demands exploring new theoretical perspectives and crafting novel methods as appropriate. This section includes chapters that focus primarily on developing new, and often interdisciplinary, theoretical foundations and enriching the methodological tools available to the science education research community.

The last section concerns designing research-based instruction. Among the main goals of science education research, one of the most important is to contribute to improving teaching practice and make research results operational, impacting education in formal and informal contexts. These general objectives become even more challenging to pursue if science education is expected to be effective in dealing with contemporary challenges. This demands designing research-based teaching materials, paths, and programs and to test them in real contexts. This section includes chapters that focus primarily on innovative instructional design or on programs to infuse formal and informal teaching with novel pedagogical principles or methods.

Highlights of the Chapters

In what follows, we will highlight the main themes addressed in the four sections by reporting how each individual chapter within each section contributes to the larger narrative of the volume, specifically, and the conference, more broadly.

Section 1: Meeting Societal Challenges

The first section launches the theme of societal challenges with the inspirational chapter by **Andri Snær Magnasson**. This chapter is not a research paper but the section could not be opened in a more appropriate way. Magnasson's particularly effective prose concerning the representational challenges we face, specifically challenges posed by the "flatness" of numerical representations, for understanding and communicating about the nature of climate change. The section continues with three chapters focusing on how science education research can help meet contemporary societal challenges of various kinds. The challenges include: (i) global environmental and health issues, (ii) the need to re-think knowledge organization by stressing interdisciplinarity for dealing with Responsible Research and Innovation, and (iii) multiculturalism and multilingualism. The last three chapters of the section engage with policy issues, examine novel curricular approaches to meet societal concerns and report on studies of science learning and instruction that focus on how learners can be prepared for meeting the pressing challenges of our time.

More specifically, after the inspirational chapter by Andri Snær Magnasson, the first research paper is by **Zeyer and colleagues** and discusses two of the first priorities citizens expect science education should address: environment and health. In dealing with these challenges, this chapter touches on the importance of educating toward an understanding of complexity, increasing systemic views and the development of comprehensive approaches to deal with these huge and problematic issues. The themes of complexity and systemic thinking are picked up in several of the pieces throughout the section and volume.

Another running theme within the volume is the issue of interdisciplinary teaching. This theme is the core of the chapter by **Fazio and colleagues**. Specifically, their paper argues that we need a perspectival change within research on Inquiry-Based Science Education (IBSE) since societal challenges and the Responsible

Research and Innovation (RRI)[1] framework require an interdisciplinary approach, if they are to be tackled in an original and suitably complex way. In their argument, the authors also stress the importance of attending to the institutional issue of improving teacher training in order to harmonize the interdisciplinary approaches across different school levels.

Finally, the fourth chapter focuses on the increased multiculturalism and multilingualism of our societies in Europe and the world. The chapter represents the panel discussion that **Espinet and colleagues** offered to the conference. With representation across a wide variety of countries, the authors illustrate an interesting range of challenges that science education research is addressing. The main challenge discussed in the chapter deals with the design and implementation of instructional approaches that make sense in these new cultural contexts. At the same time, Espinet et al. raise awareness within the research community of the forms of knowledge produced in the field of science education as we study multicultural and multilingual contexts.

After the discussion of these three main challenges, the section turns to three pieces relating to crucial policy issues. In the chapter by **Duschl and colleagues**, recommendations from four 21st Century Education Policy reports were discussed by a panel of international leaders in the science education community. The examined frameworks address curriculum, international assessments, instructional policies, and teachers' practices. The panelists specifically speculate on how models of education need to change in order to prepare students and citizens for life with uncertain global conditions and for workforce dynamics that are rapidly changing.

Then, the chapter by **Osborne and colleagues** offers a macro look at PISA data and OECD analyses to point out research orientations needed to address changes in school systems. This chapter reports a collection of four studies. Two of them represent a second layer of analysis of OECD-PISA data to discuss and check results coming from analysis carried out by OECD and from which substantive claims are made about the strengths and weaknesses of certain forms of teaching, like inquiry-based instruction. These studies argue that it is important for the research community to conduct secondary analyses of the data. The other two studies of the collection make a case for the need to avoid hyper-simplified conclusions from the data since several dimensions of complexity underlying student performance can be unpacked.

The section closes with a piece by **Bruun and colleagues**, that, in contrast to the previous chapters, offers both a more micro view of curriculum change and also tools that science education research can offer in the service of studying curriculum change. The authors focus on a specific course in Denmark called "*Basic Science Course*" in which the ministry of education has regulated that topics pertaining to scientific literacy, inquiry-based science teaching, Bildung, and interdisciplinarity should be emphasized. By applying a combination of qualitative and quantitative

[1] von Schomberg, R. (2013). A vision of responsible research and innovation. In R. Owen, J. Bessant and M. Heintz (eds), Responsible Innovation (pp. 51–74.). Chichester: John Wiley & Sons.

methods, the authors track the type of innovation incorporated in official curriculum texts and the kind of policy change they implicitly and explicitly introduce over time.

Section 2: Expanding the Evidence Base

As we have seen, section one of this book reflects the science education research community's call to action and its proclamation that it must play a role in meeting societal challenges. But if effective action is to be taken and if any challenges are to be met, this community's distinctive contribution will be to provide the needed evidence base to validate our understanding of science teaching and learning and ultimately support practical recommendations. This section includes a number of chapters that report on empirical studies examining the development of student conceptual understanding in a number of domains, learners' epistemological cognition, learners' developing self-concepts (as these relate to learning in specific domains) and learner identity. The section concludes with two chapters focusing on teachers, examining pre-service teachers' sense of "psychological distance" with respect to socio-scientific issues in the domains of health and the environment and in-service teachers' sense of self-efficacy as this relates to education for sustainable development.

The first two chapters address an important theme that has increasingly engaged the science education research community in research years: long term developmental patterns in students' understanding in a domain, often referred to as "learning progressions." This work has been important in synthesizing the large body of work on learner conceptions, putting it to the service of curriculum design and assessment. **Bernholt and Höft**'s longitudinal study examines students' developing understanding of core concepts in chemistry spanning the grade brackets 5–8 and 9–12. They make an important methodological contribution, showing how different approaches to analysing students' responses to test items lead to diverging conclusions regarding developmental patterns across grades. This work is emblematic of how carefully designed quantitative methods make indispensable contributions to our understanding of learning. Similarly, **Scheuch and colleagues** report on a longitudinal study of the development of conceptual understanding – in this case, students developing understanding of variation and change in evolutionary theory. They present case studies of three students mapping their developing understanding in this domain over the grades 8–12. This work documents students' evolving conceptions of variation and change over this period. Crucially, while improved scientific understanding can be seen over this period, non-canonical teleological, essentialist and anthropomorphic forms of reasoning persist. This work is a good illustration of how entrenched naive reasoning patterns limit student learning if not explicitly addressed in the curriculum.

The third chapter in this section, by **Tena and Couso**, examines the impact of a teaching intervention on children's conceptions of clean and polluted air, a central environmental problem in cities. This area of student understanding has not been well studied, but is very important if we are to successfully promote scientific literacy and responsible, environmentally-oriented citizenship. In this study, elementary/primary students participated in a modeling activity sequence. The results show that while most children were capable of thinking about air as a discrete substance without macroscopic differences when it is polluted, they faced difficulties in interpreting the nature of the different "particles" they identified in both clean and polluted air. These results support the view that elementary/primary school science curricula should emphasize macro and meso scale perspectives as a precursor to the later introduction of the atomic-molecular and subatomic scale.

It is now well understood that learners' epistemological understanding of the nature of scientific knowledge and knowledge change contributes to their developing conceptual understanding in science domains. Moreover, it is an important goal of science education in its own right as a central component of scientific literacy. **Kim and Alonzo**'s chapter in this section, investigates undergraduate students' evaluation of the trustworthiness of knowledge claims when considering socio-scientific issues. They show that Duncan et al.'s (2018) Grasp of Evidence framework is able to distinguish between expert and lay understanding of how to use evidence to evaluate claims. They extend this with a grounded theory analysis, identifying novel epistemic concepts not previously identified in the literature.

Learners' understanding and beliefs about themselves as learners have an important impact on their learning. Moreover, these vary considerably across learners, with gender and sociocultural variables influencing these understandings and beliefs. Understanding these influences is important if we are to ensure equity in science classrooms. **Rüschenpöhler and Markic** investigate learners' self-concept in the context of chemistry education in secondary schools in Germany. Participants included 585 students, belonging to migrant communities (mainly from Turkey). The study examined the relationships between learners' chemistry self-concept and a number of variables including gender, cultural background, learning goal orientations in chemistry, and the learners' perceptions of linguistic abilities and their social context.

The chapter by **Cavalcante and Gonsalves** broadens the perspective on science learning even further, considering how university undergraduates' science identity takes shape. Using narratives collected from three students majoring in science and participating as "local experts" in a science outreach program, the authors characterize aspects of these students' developing science identities. Central to this characterization was the notion of "science capital" understood as the scientific knowledge, understanding and social connections one has in the science community. They argue that accumulating science capital of multiple forms through early experiences and schooling leads to strong science identities. This work is important for illuminating how strong science identities are formed and to help teachers see a wider range of ways of relating to their students beyond the traditional lecture.

The last two chapters in this second section shift the focus to teachers. The first of these, by **Büssing, Dupont and Menzel**, presents the results of a survey carried out with a sample of 189 pre-service biology teachers at four different German universities. The survey was designed to explore teachers' "psychological distance" in relation to socioscientific issues dealing with the environment and health. The results capture the differences in psychological distance with regards to the SSI issues of climate change, returning wolves, and pre-implantation genetic diagnosis. The second, by **Mogias, Malandrakis, Papadopoulou and Gavrilakis**, uses a quantitative methodology to investigate in-service teachers' self-efficacy regarding education for sustainable development. This study increases our understanding of the factors affecting teachers' choices and attitudes toward how science education can contribute to a very important societal challenge.

Section 3: Developing Innovative Theoretical Perspectives and Methodologies

In order to bridge from where we are to where we must be in terms of meeting contemporary challenges, new theoretical perspectives and methodologies are needed. The first two pieces in this section, by Sherin and by diSessa and Levin, take up the issue of building theory in science education.

Sherin's piece focuses on the landscape of research on conceptual change, including taking stock of the challenges and possibilities of finding theoretical common ground in a field that has been so fraught with controversy and seemingly inconsistent findings, especially as these relate to the degree of coherence in pre-instruction conceptual understanding. Interestingly, Sherin downplays the significance of the often heated empirical debates in the field claiming that differences in results are inextricably linked to the way researchers have decided to ask questions and investigate them. Sherin argues that it is important to recognize that the field is broad and encompasses a wide range of contexts, domains, and research foci and apparently divergent findings need to be interpreted in this light. It may not be reasonable to expect uniform conceptual change processes across such a diverse landscape. However, in seeking out those places where there may be points of convergence, Sherin suggests that it would be helpful to adopt some minimal consensus language. He proposes that the constructs "elements," "ensembles," and "dynamic mental constructs" could serve this function.

In the second chapter of the section, **diSessa and Levin** reflect on the processes of building theories of learning. They draw lessons for theory building from a cross-case analysis of three quite different theories that were at different stages of development, but all of which came out of dialogue with a common orienting framework, Knowledge in Pieces (diSessa 1993, 2018). In some sense, diSessa and Levin's cross case analysis can be seen as an example of Sherin's call to action with respect to theory building emphasizing the power of a common generic language for thinking about learning that then gets specified and elaborated in particular contexts such as the nature and form of intuitive knowledge, the form of expert understanding, and processes of problem solving.

In the third chapter in the section, **Amin** explores what science education and cognitive neuroscience have to offer each other, a clear reflection of the theme of interdisciplinarity that runs throughout the volume. Amin begins by reviewing research that examines the neural underpinnings of conceptual representations and the processes of conceptual change in science learning. Amin points out how this work has not engaged with findings from the learning sciences and science education that suggest that intuitive knowledge – such as that based on sensorimotor experience – is put to use in various aspects of scientific understanding and reasoning. He hypothesizes that the same construct – image schema – is appealed to in research on science learning and in cognitive neuroscience to understand how higher level cognition is grounded in sensorimotor experience. Resonant with Sherin's call for seeking consensus constructs, Amin argues that image schemata could serve as a natural interdisciplinary bridge between research in science education and cognitive neuroscience and point the way for a productive program of research in educational neuroscience.

New methodologies are also needed. In their chapter, **Saucedo and Pietrocola** describe an innovative qualitative method they call Emotions Microsociology that can support the investigation of a challenging phenomenon, young children's emotional engagement with science. Understanding this early engagement is very important as it sets the scene for children's subsequent trajectory as science learners. Saucedo and Pietrocola's chapter illustrates the application of this method to capture a group of young children's heightened emotional engagement with a science demonstration. They show how the analytical technique illuminates children's interaction with each other, with their teacher and with the demonstration itself. Their methodology illustrates the importance of interdisciplinarity in expanding our methodological toolboxes as science education researchers.

The last chapter in this section, by **Kapon and Erduran**, analyzes curricular interdisciplinarity in STEM across three different projects. The authors offer a theoretical reflection on the different approaches adopted to crossing boundaries between science, math, and technology. The relationship between STEM interdisciplinary approaches and disciplinary teaching is explored in three different cases, with the common theoretical lens of the boundary crossing mechanisms proposed by Akkerman and Bakker (2011). They show that the boundaries between the disciplines can be crossed in several ways, with different goals and strategies. The analysis is theoretically innovative since there are many interpretations of STEM and interdisciplinarity and the authors introduced a metalevel of analysis that allowed them to compare approaches framed within different theoretical frameworks.

Section 4: Designing Research-Based Instruction

If science education is to meet contemporary challenges there will be a need for rigorous empirical research framed within existing theoretical frameworks and for innovations in both theory and research methodology. But all this research must serve the goal of developing effective innovative teaching tools and instructional approaches and these must, in turn, be subjected to empirical evaluation in real contexts. In the fourth section of the book, we include chapters that report on innovations in instructional tools and strategies and evaluate their effectiveness. These tools and strategies are shown to support the development in students of the kinds of scientific understanding, thinking skills and dispositions that they will need to meet contemporary challenges.

For example, in the first chapter in this section, **Nielsen and Brandt** report on their European project, ARsci, conducted in lower secondary science classrooms in Denmark, Norway, and Spain, which used a design-based research approach. They show how understandings related to the environment and ecology, as well as systems thinking and meta-modeling competencies can be developed in an Augmented Reality (AR) learning environment. The augmented reality environment allowed learners to take up the role of producers and engage in collaborative modeling activities, allowing them to have embodied experiences that ground and make accessible ideas that were otherwise abstract and remote.

In their chapter, **Tytler, White and Mulligan** focus on the early development of the skills of constructing, evaluating, and coordinating multiple representations, which are all central to scientific and mathematical thinking. They evaluate a lesson sequence in astronomy offered to 150 grade 1 students (6 year-olds) in two schools. In this lesson sequence, the children constructed, evaluated, and coordinated spatial representations of the movements of the Earth and Sun to make sense of shadows changing and moving throughout the day and to explain cycles of day and night. The results show the power of an interdisciplinary, guided inquiry pedagogy applying the principles of the Representation-Construction-Approach.

Next, **Buongiorno and colleagues** examine the effects of an active learning approach to teaching physics at the university level. Active learning is relatively rare at this level, but science education research is increasingly exploring ways to move away from the traditional lecture-based pedagogy that dominates science teaching at the tertiary level. The project reported here provides evidence that an innovative active learning approach can be applied across countries and contexts and that it is possible to successfully integrate conceptual understanding, problem solving and lab work in university physics instruction.

The first three chapters in this section show how innovative tools and instructional strategies can develop scientific understanding in abstract domains and help learners of various ages engage in scientific epistemic practices such as modeling, systemic thinking, constructing, and evaluating representations and laboratory investigations. But developing positive dispositions to these practices are also important. In the fourth and last chapter in this section, **Vilhunen and colleagues** examined how various instructional activities carried out within a project-based science learning unit predicted the different kinds of epistemic emotions experienced by upper secondary school students in Finland. This is methodologically challenging research requiring diverse and carefully applied methods. The authors used experience sampling, video observations and stimulated recall to investigate the participants' epistemic emotions during the implementation of the project-based learning unit. Using multi-level regression analyses, they found that initial project orienting activities were associated with positive epistemic emotions such as excitement and curiosity, whereas skills and content tasks were more associated with negative emotions such as confusion, anxiety, and frustration. As Vilhunen and colleagues point out, this research can help teachers become more aware of the emotional implications of the different design features of learning environments.

Concluding Remarks

Together, we feel that the chapters included in this volume illustrate well how the science education research community is responding to contemporary challenges. Researchers are working on many fronts: they are re-examining and evaluating current curricula, assessment, and policy of relevance to current challenges; they are conducting theory-driven empirical studies to add to our knowledge base; they are proposing novel theoretical frameworks and methodological approaches to capture the complexities of learning and instruction, that may often need to cut across disciplines; and they are designing and evaluating new educational tools and strategies. While this large body of work is multifaceted and diverse, we hope to have offered the reader a well-organized and clear view of current research in science education and we hope that you share our pleasure in the understanding that emerges.

We wish to end with a sincere thank you to the ESERA Board for the opportunity, confidence and support they provided to us in the organization of such a stimulating conference in Bologna.

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Olivia Levrini is Associate Professor in Physics Education and History of Physics at the Department of Physics and Astronomy of the University of Bologna, Italy. Her current research work concerns interdisciplinarity in STEM education, cognition and conceptual change, identity and processes of appropriation, instruction design on future-oriented STEM issues (climate change, artificial intelligence, quantum computing), educational reconstruction of advanced current topics in physics (thermodynamics, relativity, quantum physics). She currently coordinates the European Erasmus + Project called IDENTITIES (www.identitiesproject.eu) and the Horizon 2020 project titled FEDORA – Future-oriented Science EDucation to enhance Responsibility and engagement in the society of Acceleration and uncertainty (www.fedora-project.eu).

Giulia Tasquier is Junior Assistant Professor in Physics Education at the Department of Physics and Astronomy of the University of Bologna, Italy. Her research interests include design and implementation of innovative teaching materials on modern physics and SSI; the correlation between knowledge and behaviour in dealing with climate change; the role of epistemological knowledge on models and modelling in teaching/learning physics; qualitative methods of data analysis; development of strategies, tools, and activities for transforming scientific knowledge into transversal skills about the future. She is the coordinator of the national network of the Horizon 2020 project called SEAS (https://www.seas.uio.no).

Tamer G. Amin is currently Associate Professor of Science Education in the Department of Education at the American University of Beirut, Lebanon. His research focuses on conceptual change in science learning. He has been examining how the cognitive linguistic theory of conceptual metaphor can help uncover image schematic structures implicit in the language of science and how these can support and sometimes hinder learning scientific concepts. In a parallel line of research, he is investigating the challenges of teaching and learning science in the multilingual contexts of the Arab world and how these challenges might be overcome.

Laura Branchetti is tenure-track researcher of Mathematics Education at the Department of Mathematics "Federigo Enriques" at the University of Milan, Italy. She is a member of an interdisciplinary research group in physics, mathematics and computer science education in Bologna and she has been involved in European projects about STEM education and interdisciplinarity in preservice teacher training. Her main research interests concern mathematics education and interdisciplinarity in secondary school and at the transition from secondary to tertiary education; in particular she carried out research in the teaching of calculus and analysis and of the interplay between mathematics and physics.

Mariana Levin is Associate Professor of Mathematics Education in the Department of Mathematics at Western Michigan University. Her research focuses on understanding the role of knowledge and epistemic affect in moment-by-moment processes of reasoning and sense-making. Her edited volume "Knowledge and Interaction: A Synthetic Agenda for the Learning Sciences" (with A. A. diSessa and N.J.S. Brown) explores this line of work, connecting insights from diverse research traditions on learning processes as they unfold in real-time in real-world contexts. Her current work explores the development of mathematical agency and autonomy in undergraduate students' experiences in proof-intensive mathematics courses.

Contributors

Alicia C. Alonzo is Associate Professor of science education in the Department of Teacher Education at Michigan State University in the United States. She has a background in physics (with a Ph.D. in applied physics from the California Institute of Technology). Her current research broadly concerns how school science intersects with the ways that students encounter science in their everyday lives. She is interested in how school science can both leverage the ideas and experiences that students bring to the classroom and prepare students to make science-related decisions that are personally and civically meaningful.

Nuria Álvaro is a biology and geology teacher in compulsory secondary education and high school and a doctoral student in the Department of didactics of experimental and social sciences in the teacher training faculty of the University of Valencia (Spain). She is a specialist in environmental health and environmental science education. She has also authored teaching materials for the Valencia Cultural Territorial Cathedra.

Heidemarie Amon has obtained her Master in Education at the University of Vienna and has been working as a teacher of biology in Vienna since 1987. She has also cooperated with the Austrian Educational Competence Centre for Biology at the University of Vienna since 2008. Her interests include the development of competency-based learning tasks for students and biology teacher education (pre-service and in-service). In 2010, together with Dr. Patricia Hoffmeister (Jelemenská), she started to develop teaching and learning sequences on different levels of lower and upper secondary school to work with students´ conceptions about evolution.

Julia Arnold studied Biology and English for Secondary Education. After her Ph.D. in Biology Education at Kassel University, she has been a post-doctoral researcher at RWTH Aachen University and at the Leibniz Institute for Science and Mathematics Education in Kiel, Germany. Now she is head of the research group of Biology Education at the Centre for Science and Technology Education at the School of Education FHNW in Basel, Switzerland. Her research interests are in health and environmental education, inquiry learning and teachers' TPACK. In these fields she mainly focuses on the interplay between knowledge, motivational factors and actions.

Davide Azzolini is a Research Fellow at the Research Institute for the Evaluation of Public Policies of the Bruno Kessler Foundation (Italy) and Affiliated Scholar with the Urban Institute (Washington, DC, USA). He is interested in evidence-based policy and program evaluation related to student achievement, children of immigrants' education, student aid programs and the role of digital technology in learning and training. He was a Visiting Scholar at the Urban Institute and at the Office of Population Research, Princeton University.

Deidre Bauer is a research associate in biology education at Leibniz University Hannover, Germany and a teacher for biology and Latin language in a grammar school in Lower Saxony, Germany. Her research interests are knowledge and attitudes in Education for Sustainable Development (ESD).

Nicola Bazoli is a Junior Research at the Research Institute for the Evaluation of Public Policies of the Bruno Kessler Foundation (Italy). He has achieved a Ph.D. in Statistical Science at the University of Bologna. His research interests include the analysis of students' skills, with a psychometric approach, and the analysis of social inequalities in educational achievement.

Sascha Bernholt works as a research scientist at the Leibniz Institute for Science and Mathematics Education (IPN) at the University of Kiel. He studied chemistry and mathematics in a degree of education program for teaching at secondary level at the University of Oldenburg, Germany. He has a Ph.D. in chemistry education from the University of Oldenburg, Germany, and he finished his habilitation in 2020 at the University of Kiel. His research interests are largely related to students' learning and conceptual understanding and how these develop over time.

Saouma BouJaoude is presently Professor of Science Education and Director of the Center for Teaching and Learning at the American University of Beirut. His research interests include evolution education, teaching science in multilingual settings, curriculum and teaching methods, and the nature of science. BouJaoude has published in international journals such as the *Journal of Research in Science Teaching*, *Science Education*, *International Journal of Science Education*, *Journal of Science Teacher Education*, *The Science Teacher*, *Science & Education*, *Research in Science Education*, and *School Science Review*. Additionally, he has presented his research at local, regional, and international education conferences.

Amélia Branco is Assistant Professor at ISEG (ULisboa), in the Department of Social Sciences. She holds a Ph.D. in Economic and Social History. Researcher at Economic and Social History Centre (GHES/CSG – ISEG) that integrates the consortium Research in Social Sciences & Management, where she makes part of the research group Sustainability and Policy. Her main research interests are forestry value chain along the nineteenth and twentieth century, where she has several publications. Currently, she participates in two research projects: Capital Markets in Portugal (nineteenth century until WWI) and SustInAfrica – Sustainable intensification of food production through resilient farming systems in West & North Africa.

Harald Brandt is Associate Professor at VIA University College. He is teaching and supervising student teachers specialized in Physics & Chemistry and researcher at the Research Centre for Pedagogy and Education. He has been involved in various research and development projects focused in particular on technology enhanced learning in science and models and modelling. Currently, he is the Danish project leader in the EU-ERASMUS project "Ocean Connection".

Jesper Bruun is Assistant Professor at the Department of Science Education at the University of Copenhagen. He uses network analysis as a methodological tool in physics and science education research and views educational systems at all levels as complex systems.

Daniele Buongiorno is a post doc researcher in Physics Education in the Department of Mathematics, Informatics and Physics at the University of Udine in Italy. He teaches Physics for Biotechnology Students in the University of Udine and Math and Phys in Secondary School. In 2018 he received the award for the Ph.D. study on Optical Spectroscopy education in GIREP Congress. 12 papers in peer review publications characterize his research work.

Alexander Georg Büssing worked as a research assistant in the Department of Didactics of Biology at Osnabrück University (Germany) and wrote his doctoral thesis about pre-service teachers' emotions for teaching about environmental socio-scientific issues. Currently, he works at the Institute for Science Education at Leibniz University Hannover (Germany) as a postdoctoral researcher and fellow of the German Telekom Foundation in the working group for biology education. His research concentrates on the effects of emotions in digital learning environments (e.g. virtual reality and social media).

Alexandre Cavalcante is an Assistant Professor in the Department of Curriculum, Teaching and Learning at OISE/University of Toronto, Canada. His research interests are geared toward STEM education and how it can respond to contemporary socioeconomic changes in the world.

Mojca Čepič Ph.D., is Full Professor of General Physics and Physics Education. Her research is focused on two fields, on theoretical soft matter physics, more precisely on polar smectic liquid crystals, and on physics education. She has led several research projects on the introduction of new fundamental physics findings into all levels of education and their application to identifying gifted students. For several years she was Head of the Department of Physics and Technology. Currently she is Head of the Institute for Science and Arts at the Faculty of Education of the University of Ljubljana, and she acts as a chief editor of European Journal of Physics.

Digna Couso is reader at the Science Education unit at the faculty of Education and director of the research center CRECIM at Universitat Autònoma de Barcelona, Spain. Her research interests are models and modelling for the teaching of science, participatory design-research approaches for teacher education within the context and competences-based framework for STEM, with special interest in ICTs, and both equity and gender balance in STEM education. She has led and participated in a wide range of national and European projects. She is referee of some prestigious journals in field and she is also part of the expert group of PISA 2024.

Iztok Devetak Ph.D. is a Full Professor of Chemical Education at University of Ljubljana, Faculty of Education, Slovenia. His research focuses on students' learning chemistry (the influence of chemistry in context and active learning approaches), using eye-tracking in explaining chemistry learning, environmental chemistry education, developing teachers' health-managing competences etc. He was the national coordinator of PROFILES project (7th Framework Program) for 4.5 years and ERASMUS+ project Non-formal Education in Science for Students' Diversity (DiSSI). He is a Chair of Chemical Education Division in Slovenian Chemical Society and Vice-chair for Eastern Europe of European Chemical Society Division of Chemical Education.

Andrea A. diSessa holds degrees in physics from MIT (Ph.D.) and Princeton (AB). He is a member of the National Academy of Education, a Fellow of the American Educational Research Association, and Corey Professor Emeritus at UC Berkeley. His research centers on the role of intuitive knowledge in learning scientific concepts, and computational literacies. He is the prime designer of Boxer, a medium to support computational literacy. diSessa has authored over 100 articles and chapters and authored or edited seven volumes, including *Changing Minds:*

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Sara Dozier is a Ph.D. candidate in Science Education in the Graduate School of Education, Stanford University, USA. Her current research interests focus on both classroom and large-scale assessment practices and how assessment is related to issues of educational equity. She was a high school science teacher and county-level administrator in the California public school system. Her biological research focused on the molecular biology of the hypoxic response in murine models.

Mylène Duclos is a neuro-psychologist, doctoral student in Science Education at the Education Laboratory of the Ecole Normale Supérieure de Lyon in France. She is preparing a Ph.D. on the investigation of the links between the understanding and resolution of tasks related to scientific culture by students and their socio-economic-cultural status.

Jacqueline Dupont works as a research assistant in the Department of Didactics of Biology at Osnabrück University (Germany). In her doctoral thesis she is working on the sustainable consumption behaviour of children and adolescents. One research focus is the acceptance of meat alternatives such as insects and cultured meat.

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Sibel Erduran is a Professor of Science Education and Fellow of St Cross College at University of Oxford, United Kingdom. She is also Professor II at University of Oslo, Norway. She is the President of the *European Science Education Research Association*; Editor-in-Chief of *Science & Education* and an Editor for *International Journal of Science*. Her work experience includes positions in the USA, Ireland as well as the UK. Her research interests focus on the infusion of epistemic practices of science in science education. Her work on argumentation has received international recognition through awards from NARST and EASE.

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Robert Harry Evans is an Associate Professor in the Department of Science Didactics at the University of Copenhagen in Denmark. He teaches pedagogical courses for University science faculty, science Ph.D. students and undergraduates who wish to become Physics, Chemistry, Biology or Geography teachers. He supervises various levels of graduate student projects. His research interests include inquiry-based science teaching and learning and the role that self-efficacy has in facilitating inquiry and problem-based instruction. Professionally he is a member of the European Science Research Association Board with the Ph.D. summer school portfolio.

Sergej Faletič received his Ph.D. in Physics Education from the University of Ljubljana. For the past 15 years, he worked as a high school physics teacher and a researcher in the field of physics education research at the University of Ljubljana. His focus is on active engagement methods in physics education. His main work is on open-ended laboratory work and teaching and learning quantum mechanics at high school level.

Cláudia Faria is Assistant Professor at the Institute of Education, University of Lisbon. She has a background in Biology and two Ph.D., one Ph.D. in Biology – Ecology and Biosystematics and one Ph.D. in Science Education, both from the University of Lisbon. Her present research is related to the development of innovative science teaching and learning strategies in formal and non-formal contexts, such as museums, science centers, and research laboratories. She has published more than 80 scientific papers, books and book chapters. She coordinated three national research projects, related with the promotion of scientific literacy, and participated in several national and international projects.

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Odilla E. Finlayson is Associate Professor of Science Education in the School of Chemical Sciences, Dublin City University (DCU). She is one of the founding members of CASTeL (Centre for the Advancement of STEM Teaching and

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Valérie Fontanieu is a statistician at the French Institute of Education at the Ecole Normale Supérieure in Lyon (France). She is involved in several national and international research projects in science education.

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Gerald Fuchs grew up on a farm in Austria and studied biology and sports education at the University of Vienna where he also worked as a tutor for the course of outdoor education in biology teaching for several years, which meets his interest in outdoor learning. In his master thesis, written at the AECC Biology, he tried to find new aspects about the understanding of the term ‘population’ among students during the ongoing process of learning about evolution. Throughout his time at university, he has been restructuring the farm into an organic one and started breeding an old breed of sheep which was threatened with extinction.

Igal Galili holds a Ph.D. in theoretical physics from the Hebrew University of Jerusalem. His post doctorate work was in physics education at UC San Diego and UC Berkeley. Currently, he is Professor of Science Education in the Faculty of Mathematics and Natural Science at the Hebrew University of Jerusalem. His research has explored the physics knowledge of students structured in scheme-facets. He investigated representations of physical concepts and the structure of theory. He produced the paradigm of discipline-culture implied in curriculum. He argued for using artistic images to represent scientific ideas and science nature. He produced a textbook of cultural representation of light theory at schools.

Cecília Galvão is Full Professor at Institute of Education, University of Lisbon. She has a background in Biology and a Ph.D. in Education. She coordinates the Ph.D. Programme in Sustainability Science of the University of Lisbon, the Ph.D. in Education and the Joint Master Degree in Scientific Culture and Outreach of Sciences. She also coordinates the Master program on Biology and Geology teaching. She coordinates the Science Education Research Group and develops research in science education and teachers’ professional development. She was the Portuguese coordinator of EU FP6 PARSEL and FP7 SAILS projects. She is member of COST Action CA15212 Citizen Science (2016–2020).

Valentín Gavidia is honorary professor at the University of Valencia, Doctor of Biological Sciences with an extraordinary doctorate award. He is teacher of Didactics of Biology and Health Education in the Department of Didactics of