

Eilish McLoughlin  
Paul van Kampen *Editors*

# Concepts, Strategies and Models to Enhance Physics Teaching and Learning



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Eilish McLoughlin · Paul van Kampen  
Editors

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# Preface

The book presents papers selected under the leadership of GIREP vzw—the International Research Group on Physics Teaching, the organization promoting enhancement of the quality of physics teaching and learning at all educational levels and in all contexts. Through organization of annual conferences and seminars, active participation of researchers and practitioners in various GIREP Thematic Groups and wide cooperation with other international organizations involved in physics education, GIREP vzw facilitates the exchange of information and good practices in physics education, supports the improvement of the quality of pre-service and in-service professional development in physics teaching, promotes research in the field and facilitates the cooperation between stakeholders on both national and international levels.

This book is based on contributions presented at the GIREP-ICPE-EPEC 2017 conference, which was hosted in Dublin from 3 to 7 July 2017 by the Centre for the Advancement of STEM Teaching and Learning (CASTeL) at Dublin City University Ireland. This conference was organized by a collaboration between the International Research Group on Physics Teaching (GIREP); European Physical Society–Physics Education Division, and the Physics Education Commission of the International Union of Pure and Applied Physics (IUPAP). In total, 270 international researchers and practitioners from 48 countries participated in the conference and shared their knowledge and experiences under the theme of Bridging Research and Practice in Physics Teaching and Learning. A wide variety of topics and approaches, conducted in various contexts and settings, all adding a strong contribution to the field of physics education research were presented during the week-long conference. Examples include the design of curriculum and strategies to develop student competencies—including knowledge, skills, attitudes and values; inquiry workshop approaches in teacher education and pedagogical strategies adopted to engage and motivate students. Overall, a total of 271 contributions were presented—including 6 invited keynotes and 154 oral presentations, 40 symposia

(each with four papers), 12 ICT demonstration/workshop sessions and 59 poster presentations. This book is built on 20 papers carefully selected in a rigorous double-blinded peer-review process, involving members of the editorial board and additional referees in order to guarantee the quality of the content of this contribution.

This collection of 20 chapters is presented in four parts, each with a focus on a particular aspect of research and practice in physics teaching and learning.

**Part I: Development of Physics Teaching and Learning in School** discusses a range of different models and strategies used to improve the teaching and learning of physics concepts in the classroom. Approaches include the introduction of the concept of voltage as an electric pressure difference across a resistor in an electric circuit, the use of graphical and visual analogies and models to introduce Einstein's General Theory of Relativity and a virtual sandbox which incorporates a combination of real-world experiments and real-time computer simulations to introduce the principles of granular flow physics. The Teaching Enquiry with Mysteries Incorporated (TEMI) approach designed for teaching concepts at second level was extended to develop classroom materials for teaching colours, gas behaviour and magnetism in primary schools. The last contribution in this part proposes that mathematics in modern school could be considered more as a "quasi-natural science" and asks how this approach may change teaching strategies.

**Part II: Innovation in Undergraduate Physics Education** presents teaching and learning of advanced physics topics based on and contributing to physics education research: the quantum Hall effect through the 5E model, a discussion of the foundations of thermodynamics, a carefully sequenced set of experimental activities concerning the photoelectric effect and quantum efficiency and the effect of introducing skills-oriented laboratories.

**Part III: Trends in Physics Teacher Education** explores how teacher education is changing to accommodate and promote different ways to teach and learn. A recurring theme is teachers assuming the role of their students as they develop an understanding of a variety of teaching approaches: they engage in role play about energy exchange, undertake inquiry into socio-scientific issues or experience a range of activities across the inquiry spectrum. Teachers reflect on learning sequences through critiquing them, and on classroom interactions through studying video recordings. The impact of teachers' views on the relation between mathematics and physics is also discussed.

**Part IV: Bridging Gaps in Student Motivation and Engagement in Physics** considers approaches that bridge the gap between formal, informal and non-formal learning environments and can lead to increased student motivation and engagement as well as increased awareness of careers and further programmes in physics.

It is our sincere hope that this collection of papers presents insights into current research in physics education at the end of 2017 and will be of interest to physics teachers, teacher educators and physics education researchers around the world with a commitment to bridging research and practice in physics teaching and learning.

The editors are grateful to the authors for their hard, fruitful work and to all the reviewers for their valuable remarks and time devoted to the development of the community of physics researchers and practitioners.

Dublin, Ireland

Eilish McLoughlin  
Paul van Kampen

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## About the Editors

**Eilish McLoughlin** is an Associate Professor in the School of Physical Sciences and Director of the Research Centre for the Advancement of STEM Teaching and Learning (CASTeL) at Dublin City University. She received her Ph.D. in Experimental Surface Physics in 2000. Her research interests are focused on the development of curriculum, instruction, and assessment models in Physics/STEM education, at all levels of education, from primary school to Ph.D. level. She has led and collaborated on many research projects at EU, national, and local levels, including coordination of EU FP-7 project ESTABLISH and partner in EU projects 3DIPhE, OSOS and SAILS. She co-leads the physics initial teacher education programme at Dublin City University and has led several projects that support teachers, both in-service and pre-service, in adopting innovative practices in their classrooms and enhance student identity in Physics/STEM. She has received recognition for her leadership in STEM Education and engagement across formal and informal contexts: including the NAIRTL National Award for Teaching Excellence (2010); Institute of Physics Lise Meitner Medal (2018) and Institute of Physics Young Professional Physicist of the Year (2006) and Dublin City University's President Award for Public Engagement (2017) and for Teaching and Learning (2005).

**Paul van Kampen** is an Associate Professor in the School of Physical Sciences at Dublin City University and researcher within the School of Physical Sciences and the Centre for the Advancement of STEM Teaching and Learning (CASTeL) at Dublin City University. He obtained a Ph.D. in experimental atomic physics. His current research interests are divided between research-based development of teaching–learning sequences in university level physics and science teacher education. The focus in both areas is on how students develop scientific understanding and reasoning. He teaches physics and physics education at undergraduate and postgraduate level, and is heavily involved in science teacher education. His

teaching is strongly influenced by his physics education research, which focuses on the development of research-led and research-validated educational materials. He was awarded the NAIRTL National Award for Excellence in Teaching Award for Excellence in Teaching and Learning in 2012. He chairs the Irish National Council for Curriculum and Assessment's Development Group for Junior Cycle Science.

## Contributors

**Antonio Amoroso** holds a Ph.D. in Nuclear Physics at the University of Turin and is currently a research technician at the Department of Physics. He is member of the COMPASS collaboration at CERN since 2001, with research activities focused on spin physics and Drell-Yan process. He is member of the BES3 collaboration at IHEP since 2012, with research activities focused on CGEM (Cylindrical GEM) detector project. He also collaborates to the activities of the research group in history and didactics of physics, with a focus on the laboratory activities for secondary schools. He is the curator of the Museum of Physics of the University of Turin. For the academic year 2018–19, he will be teacher of the Physics module at the Physical education bachelor's degree and the Laboratory of Fundamentals and Didactics of Physics module of the Master's degree in primary education of the University of Turin.

**Esther Bagno** is a Senior Staff Scientist in the Science Teaching Department and has a major role in the research and development activities of the Physics Group. Her aim is to raise the quality of learning and teaching in Israeli high schools. Her work builds on her first-hand experience as a physics teacher for 17 years and own research. A major strand in her work has been the design, implementation and study of professional development frameworks for physics teachers aimed at nurturing teachers' professionalism (e.g. their knowledge of physics and physics teaching). She has been the director of the National Center for Physics Teachers since its establishment in 1995. She collaborates closely with the Israeli Ministry of Education and serves on several of its committees devoted to physics learning and teaching. She lectures and leads workshops and courses and serves on graduate programme committees.

**Ami Baram** is a psychodrama director and documentary film creator. His films and photographs were broadcast on the Israeli channel 2 and 10 and exhibited at the Israel museum, Jerusalem. He has varied experience in group directing—social groups, professional teams and therapeutic dynamic groups. He served as a teacher in the Kibbutzim College of Education Technology and Arts, Art high school and in a special programme for youth at risk. He has an ongoing interest in the interdisciplinary connection between education, documentation and group directing. He is the developer and co-director of “Video-didactic”—a project designed to develop

physics and mathematics teachers' proficiency in conducting a peer video-based didactic discourse. He graduated from the Sam Spiegel Film School, Jerusalem, and the Kivunim Institute for Psychodrama and Group Work.

**Sara Roberta Barbieri** teaches mathematics and physics at high school. She graduated in physics with a thesis on mathematical models for the characterization of biophysical systems and she obtained a Ph.D. with a thesis on how to teach superconductivity at high school using mainly electromagnetic integral operators. From 2011 to 2017, she was in detachment to the physics department of the University of Milan, with which she is still collaborating. She conducts researches in the field of physics education in the context of electrical conduction, superconductivity and harmonic oscillations. She writes and illustrates stories to present physics in primary school and designs teacher training activities to introduce enquiry teaching at high school.

**Leonardo Bellomonte** is an Associate Professor of Solid State Physics (retired) at the University of Palermo. He has spent 2 years as a research associate at the University of Southern California, Los Angeles. He is a senior member of the American Physical Society (APS). His main field of research has covered paramagnetic resonance, lattice dynamics and optical absorption in solids. Other fields of research have concerned medical physics (mainly computer-based diagnosis of ocular states and/or pathologies); educational physics (devoted to the diffusion and implementation of computer-based teaching methods); computer simulation of various properties of matter such as the low temperature behaviour of the specific heat, etc.

**Jan-Philipp Burde** earned his Ph.D. in physics education research at Frankfurt University in Germany, where he developed and empirically evaluated a new curriculum to teach electricity in lower secondary schools. Prior to joining academia, he did his teacher training in the UK and gained qualified teacher status (QTS) to teach in schools in England. He also holds a graduate degree in Physics and English with a concentration in teaching and education from the University of Kassel, Germany. His research interests include the development of new teaching concepts, the use of computers in physics teaching and the effectiveness of context-based physics instruction.

**Ruth Chadwick** is a postdoctoral researcher and lecturer in initial teacher education. Her research interests include learning and teaching methodologies for science education, and curricular policy development. She completed her undergraduate degree in Zoology and subsequently obtained a PGCE in secondary education in science and biology. She worked for a number of years as a secondary school teacher in Scotland, during the introduction of the Curriculum for Excellence. From this, she gained an insight into curricular policy development from the "chalk-face". She completed a Ph.D. in 2018 with a thesis entitled "Development and Assessment of Scientific Literacy for Secondary Level Science

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**Federico Corni** is Professor of Didactics of Physics at the University of Modena and Reggio Emilia. From February 2019, he will take up a position in the Faculty of Education at the Free University of Bolzano. He teaches physics to prospective kindergarten and primary school teachers and trains groups of in-service teachers in various schools. His research focuses on conceptual metaphor in building and assessing scientific concepts and narrative approaches to physics and science teaching. He is author of journal papers and editor of “Le scienze nella prima educazione. Un approccio narrativo a un curriculum interdisciplinare” (Erickson, Italy, 2013).

**Anna De Ambrosis** is Associate Professor in Physics at the Physics Department of the University of Pavia (Sector FIS/08 Physics Education and History of Physics). From 1988 to 1991, she worked at the University of Ferrara and since 1991 at the University of Pavia. She served as coordinator, for Mathematics and Physics, of the Postgraduate School for Teachers’ Preparation at the University of Pavia and for Physics in the Postgraduate Teacher Training Course (TFA). Her scientific interests lie in Physics Education. Research in this field has been developed along various lines: the role of computer simulations, correlated to students’ experimental activity, in the formalization process; the use of MBL tools and new technologies to favour the teaching/learning of physics at different school levels; the introduction of topics of modern physics, in particular special relativity and quantum physics, in the high school curriculum; the design and implementation of models and strategies for secondary school physics teachers preparation. The research has been carried out within national and international projects.

**Claudia De Grandi** recently joined the Physics and Astronomy Department at University of Utah as an Assistant Professor of Educational Practice. One of her main roles is to implement and promote evidence-based teaching pedagogies in introductory physics courses and improve the teaching quality and inclusiveness of physics and STEM courses more broadly. She works closely with Learning Assistants and Teaching Assistants to create effective instructional teams. At University of Utah, as well as previously as a Teaching Postdoc at Yale University, she has been working to reform the Introductory Physics curriculum for Life Sciences majors (pre-medical students and biology majors), both the lecture courses, as well as the laboratory ones. Her background is in condensed matter theory; she obtained her Ph.D. from Boston University studying quantum systems of cold atoms, and then pursued research on quantum information during her postdoctoral time at Yale University.

**Bat-Sheva Eylon** is a faculty member of the Science Teaching Department at the Weizmann Institute of Science (WIS), and acted as its head in 2008–2015. She is a Fellow of the AAAS, recipient of the Israeli EMET Prize in Education for 2015 and pedagogic head of the Rothschild-Weizmann M.Sc. Program for Excellence in Science Teaching. She studies the learning and teaching of physics and physical sciences in secondary schools and a major focus has been the long-term professional development of teachers in professional learning communities, presently implemented in grades 7–12 all over Israel. She co-authored with Linn the book: *Science learning and instruction: Taking advantage of technology to promote knowledge integration* (2011). She holds a B.Sc. in physics and mathematics from the Hebrew University of Jerusalem, an M.Sc. in physics from the WIS and a Ph.D. in science education from Berkeley University in the US.

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**Enrico Giliberti** is a researcher in Didactics and Special Education at the University of Modena and Reggio Emilia. He teaches education technologies and group work methodology in a primary school teacher degree course; didactics, special education and education technologies in an educator degree course. He trains groups of in-service teachers in the subjects of science education and playing/table gaming. His research focus is on conceptual metaphor in building and assessing scientific concepts and narrative approaches to science teaching in primary school and the role of playing as a tool for knowledge. He is a member of the scientific committee of the Research Centre for Metaphor and Narrative in Science ([www.manis.unimore.it](http://www.manis.unimore.it)).

**Marco Giliberti** graduated in physics at the University of Milan with a thesis on the foundations of quantum physics. He is a researcher at the same university where he teaches “Preparation of Teaching Experiences 1 and 2” and “Relativity”. He is responsible for the Scientific Degree Plan (Physics) at unimi. He obtained the national scientific qualification to associate professorship in 2017. He performs research in quantum physics education, in physics teaching through theatre and in teacher training. He is the author of about 60 publications in national and international journals, the book “Physics at theater”(Aracne editrice, 2014) and the monography “Peter Higgs” (Grandangolo Scienza–Corriere della sera, March

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**Mark D. Greenman** is a Research Fellow in the Department of Physics College of Arts and Science, Boston University. He serves as co-PI and director of Project Accelerate NSF#1720914 and is co-PI on Project PSUNS Robert Noyce Teacher Scholarship Program NSF#1660681. He is a past Presidential Awardee for Excellence in Science Teaching, Janet Guernsey Awardee for Excellence in Physics Teaching, and served 2 years as an Einstein Fellow at the National Science Foundation Division of Undergraduate Education. His undergraduate physics degree is from Hofstra University and graduate physics degree from Syracuse University. A passion for physics and physics teaching and learning are hallmarks of his career.

**Claudia Haagen** is Full Professor at the institute of Physics at the University of Graz where she is the department’s Chair for Physics Education and deputy director of the institute. Claudia Haagen has 8 years of experience as high school teacher. She earned her Ph.D. in Educational Sciences at the University of Graz. In 2016, she completed her habilitation in physics education and gained the *venia docendi* for didactics of physics at the University of Vienna. In 2017, she was awarded the Josef-Krainer-Würdigungspreis—a highly competitive science prize—for her habilitation, a design-based research project on teaching and learning introductory optics for year 8. Professor Haagen’s research interests lie in the area of content specific teaching and learning processes and conceptual change, professional development of teachers and language in science teaching.

**André Heck** earned M.Sc. degrees in mathematics and chemistry, and a doctoral degree in mathematics and science education. He is a senior lecturer at the Faculty of Science of the University of Amsterdam, teaching in particular mathematics and physics to life science students. His main research area is the application of ICT in mathematics and science education.

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**Andrea Kárpáti** is Professor and UNESCO Chairholder at Eötvös Loránd University, Faculty of Science, Centre for Science Communication and Multimedia in Education. She is Head of the Visual Culture Research Group of the Hungarian Academy of Science and ELTE University. Her teaching and research activities involve visual culture of children and adolescents, digital literacy in education, museum learning and synergies of science and arts education. Her recent research projects include EU-funded EnVIL (developing the European Framework of Visual Literacy), Moholy-Nagy Visual Modules (a curriculum innovation project) PARRISE (representing socially sensitive issues in science communication) and KP-Lab (developing collaborative pedagogical scenarios).

**Andrea Király** is a physicist and a teacher of mathematics and physics. She obtained her Ph.D. in Statistical Physics with a thesis entitled “Long-range correlations in daily temperature records”. She is Assistant Professor at ELTE Eötvös Loránd University, Faculty of Science, Centre for Science Communication and Multimedia in Education. She is head of the Science Centres and Informal Learning Working Group of the MTA-ELTE Physics Education Research Group established by the Eötvös Loránd University and the Hungarian Academy of Sciences in 2016, and was head of the Hungarian team in the PARRISE (Promoting Attainment of Responsible Research and Innovation in Science Education, 2014–2017) EU FP7 project.

**Inkeri Kontro** obtained her Ph.D. in the field of Materials Physics in 2016 from the University of Helsinki, where she currently works. She has also been a visiting researcher at the Niels Bohr Institute, Copenhagen. During her Ph.D., she started working on the development of introductory and intermediate physics courses. Her research interests in Physics Education Research are the development of content knowledge and its interplay with student attitudes towards physics.

**Eduard Krause** studied mathematics and physics at the University of Siegen (Germany). In 2013, he received his doctorate in the field of physics education research. He was appointed as Assistant Professor at the Institute of Mathematics education research in Siegen in 2014. In 2015, he was a guest lecturer at the Hanoi National University of Education (Vietnam). In 2016, he held a professorship at the University of Cologne and in 2018 at the Friedrich Schiller University in Jena. His research interest lies in the didactic implications resulting from the synergies between mathematics and physics. In this area, he successfully leads international projects.

**Alessandra Landini**, Ph.D. student in Human Sciences and Didactic of Physics at University of Modena and Reggio Emilia, is a primary school teacher and teacher educator and collaborates with the Centre for Metaphor and Narrative in Science. Her research includes the use of narrative, metaphorical expressions and gestures in

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**Yaron Lehavi** is a physics teacher, a senior lecturer, the head of the Research and Evaluation Authority at the David Yellin Academic College of Education and head of the National Center for Physics Teachers at the Weizmann Institute of Science in Israel. He has a long experience in teachers' training, development of learning materials, curriculum development and scientific and educational counseling. He is the developer and co-director of "Video-didactic"—a project designed to develop physics and mathematics teachers' proficiency in conducting a peer video-based didactic discourse. His research covers such areas of physics education (at various levels) as conceptual understanding of physical concepts, teachers' PD and the Phys-Math interplay. At the beginning of his career, he served as a high-school physics and mathematics teacher. He holds a B.Sc. in physics and mathematics, an M.Sc. in physics and a Ph.D. in science education from the Hebrew University of Jerusalem.

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**Massimiliano Malgieri** is a postdoctoral researcher in the field of Physics Education at the University of Pavia. He graduated in Physics in 2003 at the University of Genova, where he specialized in teaching physics and mathematics in high school. He then worked for several years as a school teacher before returning to University to obtain his Ph.D. In 2015, at the University of Pavia, he successfully defended his Ph.D. thesis, titled "Teaching quantum physics at introductory level: a sum over paths approach". Since 2015, he is working in Pavia as a postdoctoral researcher and contract professor for courses such as Physics Education and Preparation of Educational Experiences. He is mainly involved in research and projects related to improving the teaching of modern physics at secondary school level, designing and disseminating innovative teaching–learning sequences and laboratory experiments, exploring the role of games and simulations in the learning process. He is the author of more than 20 articles in international journals indexed

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**Daniela Marocchi** was Associate Professor of Experimental Physics at the University of Turin from 1985 to 2016. She had been President of the Master Degree in Physics, University of Turin responsible of the National Science Degree Project (PLS) since the beginning of the project, and referent for the Physics qualification courses for secondary school teachers. She encouraged the research in physics education at the Department of Physics of the University of Turin by proposing a master degree course more fitting to the needs of future teachers. She was supervisor of several master's theses in physics education and she is currently collaborating to a Ph.D. project in History and Didactics of Physics. For the academic year 2018–19, she will be teacher of a module on Educational Methodologies and Technologies in Physics at the Master Degree in Physics.

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**Pasquale Onorato** is associate professor at the University of Trento. He graduated in Physics in 1998 at the University of Napoli where in 2001, he successfully defended his Ph.D. thesis. In 2001, he moved to the Frascati National Laboratory of the INFN. Then, he was postdoctoral researcher in the Physics Department of the University of Pavia, Italy, working with the Physics Education Research group. Since 2015, he works at the Department of Physics, University of Trento in the Laboratory of Physical Science Communication. He is author or co-author of more than 90 scientific papers in international ISI-Scopus indexed journals and of

several contributions to national and international conferences. He is actively involved in investigations about physics education, and the use of technology to enhance learning physics, and was also interested in researches on theoretical condensed matter. His main research interests are students' conceptions and reasoning; design and experimentation of innovative teaching–learning sequences; modern physics instruction; strongly correlated electron systems in low dimensions; carbon-based nanostructures (nanotubes, graphene, etc.); spin effects in low dimensional electron systems: spin Hall effect and spintronics, and Raman spectroscopy.

**Dominique Persano Adorno** holds Ph.D. in Applied Physics, Assistant Professor of Solid State Physics and is a member of the Physics Education Research Group at the Department of Physics and Chemistry of Palermo University. Her research interests include the study of nonlinear dynamics of complex systems in condensed matter physics and applied physics (spin and charge transport phenomena, 2D materials and graphene, polymer translocation, cell growth, etc.). Recent investigations deal with the design and implementation of inquiry-based learning environments for the development of effective strategies to teach physics at school and university level. She is involved in research projects concerning Inquiry-based Science Education, innovative e-learning scenarios, collaborative learning, ICT for enhanced learning. She is the author of more than 60 papers in ISI/Scopus indexed journals; 5 book chapters; over 50 refereed proceedings to international conferences. She is a member of the Editorial Board of PLOS ONE, Cogent Physics, International Journal of Biomedical Engineering and Science, Applied Physics Research.

**Nicola Pizzolato** is a physics teacher at secondary school and researcher focused on applied physics in Palermo, Italy. He earned an M.Sc. in physics (astrophysics) in 1997 from the University of Palermo. He was a visiting scientist from September 1999 to March 2000 at the Harvard-Smithsonian Center for Astrophysics-Cambridge, USA, to study the calibration data from the CHANDRA X-ray space telescope. He received a Ph.D. in physics from the University of Palermo in 2002 and worked as a postdoctoral fellow at the Palermo Astronomical Observatory. More recently, he focused his work on the field of Physics Education Research. He earned a second Ph.D. in Physics Education in 2014, defending a thesis about the development of effective strategies of teaching–learning science in upper secondary school and at university level, by following an inquiry-based approach to physics education. He has published more than 80 scientific publications, including about 40 papers in ISI journals.

**Gesche Pospiech** is Full Professor of physics education at the Faculty of Physics of the Technische Universität Dresden in Germany. Her main research interest concerns Modern Physics in secondary school with a focus on quantum theory with a modern approach. Her second field of research is mathematics in physics education with emphasis on secondary school. In addition, she studies the pedagogical

content knowledge of teachers in this field. She has been part of European projects fostering the science interest of students and in the Network Particle world in Germany. In addition, she is responsible for the physics education training of teacher students at TU Dresden.

**Stefan Radl** holds a Ph.D. in chemical engineering from Graz University of Technology (TU Graz) and was promoted with highest distinction (*promotio sub auspiciis Praesidentis rei publicae*) in 2011. The topic of his Ph.D. was “Modeling of multiphase systems in pharmaceutical applications”, the thesis was supervised by Prof. Johannes Khinast. Prior to this, he received a Diploma (Master of Science) in chemical engineering from TU Graz, with a thesis on the modeling of bubbly flows. Since 1 August 2018, Stefan is an Associate Professor at TU Graz, where he holds a *venia docendi* for the subject “particle technology”. Prior to that, Stefan was a Post Doc at Princeton University (Department of Chemical and Biological Engineering, supervisor: Prof. Sankaran Sundaresan, 2011 to 2012), and an Assistant Professor at TU Graz (from 2012 to 2018).

**Rona Ramos** is a Lecturer and instructional lab manager in the department of physics at Yale University. She holds a B.S. in physics from UC, Berkeley, a masters in physics from UCLA and a Ph.D. in applied physics from Yale University where she developed techniques for the MRI of solids. Dr. Ramos teaches introductory physics courses and is also involved in training postdoctoral and graduate students in active learning and inclusive teaching methods based on cognitive science and physics education research. She is also co-director of Girls Science Investigations, a Yale outreach programme encouraging middle school girls to pursue careers in science.

**Jakob D. Redlinger-Pohn** studied Chemical and Process Engineering at Graz University of Technology. His diploma work was related to the drying of dense and wet particle slurries. In his Ph.D. work, which was defended 2018, he studied the size dependent clustering of particles (here cellulose fibres) and selective removal of smaller (here shorter) particles. During his Ph.D. work, he lectured class and lab courses on the handling, description and manipulation of particles and particle assemblies.

**Erich Reichel** received a diploma for teaching physics and mathematics at grammar schools at the University of Graz. Afterwards, he was Assistant Professor at the Institute for Experimental Physics in the field of lasers in medicine and was promoted in biophysics (Ph.D., 1984). From 1992 to 2013, he was a high school teacher of physics and mathematics at the BG/BRG Seebachergasse in Graz. In parallel, he was a partner in national and international school projects (Comenius, FP7) and was Lecturer in physics at the University of Graz and the University College of Technology (FH Joanneum, Graz). During this time, he was also responsible for Styrian physics teachers and their in-service education. In 2013, he moved to the University of Teacher Education of Styria as a university college

professor for didactics in science and technology. He is currently setting up NATech (Center for Didactic Research in Science Education).

**Marta Rinaudo** is Ph.D. student in Physics and Astrophysics, at the University of Turin (Italy), with a project on the history of physics and physics education titled “Towards an integrated Museum of Physics in Piedmont”. After graduating, she planned and implemented hands-on laboratory activities for physics education at primary and secondary schools and participated in the e-learning project offered by the Department of Physics. She had been teacher at the Laboratory of Fundamentals and Didactics of Physics module of the Master degree in primary education of the University of Turin. As part of her Ph.D. project, her current research activities are carried out at the Museum of Physics of the University of Turin, with the main focus on studying the origins of the old Physics Cabinet and developing educational activities based on the collection of historical instruments. Also, she is actively working on the establishment of a regional network of school museums of physics with the goal of discovering the educational value of the historical scientific heritage.

**David Sands** studied Applied Physics at the University of Bradford, graduating in 1982 with a First Class Honours degree. He stayed on at Bradford to research electronic characterization of semiconductor interfaces, achieving his Ph.D. in 1987. He moved to the University of Hull in 1990 and continued to work on electrical characterization of semiconductors for a while, but gradually concentrated more on laser processing. Whilst at Hull he also developed a strong interest in physics education and in September 2004 was awarded a University Teaching Fellowship. This was a competitive award designed to mirror the National Teaching Fellowship at that time. David was awarded his NTF in 2015. He is currently Director of Learning and Teaching for the School of Mathematics and Physical Sciences at Hull. He chairs the Degree Accreditation Committee of the IOP, the IOP Higher Education Group and the Physics Education Division of the European Physical Society and also represents the UK on Commission C14 of IUPAP (ICPE). As well as his interest in physics education, he has pursued a strong interest in the foundations of thermodynamics and continues to work in this field today.

**Ruti Segal** is a mathematics teacher educator and served as a high-school teacher of mathematics for 26 years. She also served as an assistant to the national superintendent of high-school mathematics in Israel. She is a Lecturer at Oranim College of Education and at Shaanan College of Education. She integrates technology in mathematics instruction and research. Her research focuses on professional development of mathematics teachers and mathematics teacher educators. She serves as an academic advisor at the Weizmann Institute for “Video-didactic”—a project designed to develop physics and mathematics teachers’ proficiency in conducting a peer video-based didactic discourse. She holds a B.Sc. in mathematics and computer sciences from the Haifa University, an M.Sc. in teaching science focus in mathematics from the Jerusalem University-Givat Ram,

and a Ph.D. in teaching science focus in mathematics from the Technion - Israel Institute of Technology.

**Verena Spatz** is a Junior Professor at the Institute of Physics at the TU Darmstadt. After she had completed her studies of mathematics and physics with honours, she earned her Ph.D. in physics education research at the LMU Munich in 2010. Over the next 5 years, she was a teacher at several German high schools and an external lecturer at the University of Bamberg. Then she spent one year as a postdoctoral researcher at the University of Vienna in the Austrian Educational Competence Centre Physics. She was awarded the Science Prize (University of Augsburg) in 2008 and the Polytechnic Prize (Polytechnic Society of Frankfurt) in 2011. Her main research interests are processes of conceptual change, implementation of instructional innovation as well as effects of mindsets on science teaching and learning.

**Warren B. Stannard** is presently working within the Australian Education system to assist high schools introduce technology programmes into the curriculum. He has a Ph.D. in Physics (materials analysis by nuclear techniques) and a Masters by research in a similar field. Recently, he completed a project at the University of Western Australia to evaluate student responses to the introduction of Einsteinian Physics early in their educational life. He has worked as the science education officer at the Gravity Discovery Centre in Gingin, Western Australia. He has previously worked as a Lecturer in Physics at Edith Cowan University and taught at Deakin University, delivering lectures in Engineering Physics, Machine Dynamics, Principles of Thermodynamics, Materials Science and Engineering Design.

**Péter Tasnádi** is a retired professor of the Eötvös Loránd University, Faculty of Science. He was the Deputy Dean of Education Affairs of the Faculty of Science for 10 years and the President of the Centre of the Science Education Methodology of the Faculty of Science. His teaching activity involves introductory physics courses, lectures on teaching methodology and laboratory courses in teacher training, as well as dynamic meteorology and atmospheric physics for graduate and postgraduate students in meteorology. His research field is the methodology of physics teaching, metal physics and atmospheric physics. Besides research papers, he has written a number of textbooks for secondary school and university students.

**Onne van Buuren** is a physics teacher at a Dutch school for secondary Montessori education, a developer of instructional materials for secondary physics education and an educational researcher. In 2014, he obtained his doctoral degree in Physics Education at the University of Amsterdam, with a thesis on the development of a modelling learning path for lower secondary physics education. Since 2018, he is also a physics teacher trainer at the Vrije Universiteit Amsterdam.

**Thomas Wilhelm** graduated from grammar school in 1989, studied at the University of Würzburg and then completed the practice teaching period. After this, he worked for several years as a teacher at grammar school. This was followed in 2000 by a time as a research assistant at the University of Würzburg (with the conferral of a doctorate in 2005). In 2011, the habilitation was completed. In 2011, Prof. Wilhelm accepted a professorship at the University of Augsburg and in 2012 a professorship at the University of Frankfurt, where he has been the Executive Director of the Department for Physics Education Research since 2014.



**Part I**  
**Development of Physics Teaching and**  
**Learning in School**