Yifat Ben-David Kolikant
Dragana Martinovic
Marina Milner-Bolotin *Editors*

STEM Teachers and Teaching in the Digital Era

Professional Expectations and Advancement in the 21st Century Schools

Springer

STEM Teachers and Teaching in the Digital Era

Yifat Ben-David Kolikant
Dragana Martinovic • Marina Milner-Bolotin
Editors

STEM Teachers and Teaching in the Digital Era

Professional Expectations and Advancement in the 21st Century Schools

Springer

Editors
Yifat Ben-David Kolikant
Seymour Fox School of Education
Hebrew University of Jerusalem
Jerusalem, Israel

Dragana Martinovic
Faculty of Education
University of Windsor
Windsor, ON, Canada

Marina Milner-Bolotin
Department of Curriculum and
Pedagogy, Faculty of Education
University of British Columbia
Vancouver, BC, Canada

ISBN 978-3-030-29395-6 ISBN 978-3-030-29396-3 (eBook)
https://doi.org/10.1007/978-3-030-29396-3

© Springer Nature Switzerland AG 2020
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
The publisher, the authors, and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Switzerland AG.
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

> *A person has STEM literacy if she can understand the world around her in a logical way guided by the principles of scientific thought. A STEM-literate person can think for herself. She asks critical questions. She can form hypotheses and seek data to confirm or deny them. She sees the beauty and complexity in nature and seeks to understand. She sees the modern world that mankind has created and hopes to use her STEM-related skills and knowledge to improve it*. [Professor Richard Larson, M.I.T.]

In this brief commentary paper, I will seek to give my contribution to the issue presented in this book, attempting to situate the given discussion in a global way and to offer a short broad view on STEM. In particular, I will refer to what is happening in Europe, and especially in my country, Italy, with the aim of highlighting how the topics examined in this book overlap the geographical boundaries of the countries in its sights, Canada and Israel.

With this purpose, I will start by underlining that, albeit there is not a shared definition of the meaning of the acronym STEM (Science-Technology-Engineering-Mathematics), in recent years, this term has become a catalyst for various reflections concerning the concept of technological innovation and education. The reasons might be found in the outcomes of international comparative assessments (e.g., OECD, 2013) and in the reported poor preparation of students for new high-tech jobs that were started to catch a glimpse of the horizon. The scenario that emerges is often of a general slowdown in the race to update skills, with a chronic slow-going reaction in countries that have historically a difficult relationship with scientific subjects. If, for instance, European students seem, with some exceptions (e.g., Finland or Germany), currently almost unprepared to grasp the opportunities of future STEM jobs, in some cases, as in Italy, the situation is also aggravated by a general fall in graduates and university students, well below the European average. Observers and industry experts agree on identifying the main root of this problem in the design of school systems, still not adequately equipped to stimulate engagement in STEM disciplines. It is often stressed, indeed, that the STEM profiles are the most requested by innovative and competitive companies but also the most difficult for them to find, and this is also linked to the speed with which professional roles change. According to the World Economic Forum[1], it has been estimated, indeed, that 65% of children starting primary school will do a job that does not exist today. The interest in STEM workforce perspective, hence, is strictly connected to the urgency to improve STEM education at school, and this has shifted the focus, from being associated with the particular collection of disciplines to advocacy of interdisciplinary curriculum practices built around authentic problems which involve some or all of them (Tytler, Swanson, & Appelbaum, 2015). The skill-sets students need in the era of change are seen to be more related with critical and creative thinking, problem solving, and digital literacy, which are perceived as drivers of innovation. This impacts the role of STEM teachers in the twenty-first century as they are asked to cope with cognitive, behavioral, and social effects of students' life with technology.

To present a global view on STEM, I will make large use of data coming from the Australian Final Report of a project aimed at critically examining approaches to STEM capacity building in several countries and regions across the world (Marginson, Tytler, Freeman, & Roberts, 2013). The report firstly underlines that, while the countries that have strong STEM education (such as Finland, China, Korea) have diverse economies, political and social cultures, and educational traditions, they have some recurring commonalities (p. 15). Firstly, in these countries school teachers enjoy high esteem, are well paid, and work within meritocratic career structures. Secondly, in these countries there is a strong commitment to disciplinary contents, so that teaching and consequently professional development are primarily focused on the knowledge of the discipline. Thirdly, the curriculum and pedagogy have been reformed to focus on making science and mathematics more engaging and practical through problem-based and inquiry-based learning. Fourthly, creativity and critical thinking are consistently emphasized. Fifthly, innovative policies have been developed to lift STEM participation among formerly excluded groups. Finally, strategic national policy frameworks have been developed to stimulate favorable conditions for a range of STEM activities.

In Europe, STEM is especially significant in advanced manufacturing nations such as Germany, where engineering has a large presence. Finland has exceptional STEM indicators in all domains including school performance, the proportion of doctoral enrolments, the level of the STEM qualifications required at work including teaching, and the weight of the research and development workforce within the economy. Most of the European countries have national STEM (or science) policies or strategies (Eurydice, 2011) that provide a coherent STEM framework, frequently linked to broader educational goals. Typically, these policies or strategies involve promoting a positive image of science, increasing public knowledge of science, improving school-based mathematics and science (teaching and learning), and increasing interest and participation in school-based mathematics and science, tertiary STEM disciplines, and the STEM workforce.

---

[1] www.weforum.org

In 2009, lagging behind the USA and some other countries and behind the growth of the high-tech industry, Europe has started to stir things up establishing a network named Scientix[2], so as to not leave European science-related school projects isolated and to create a critical mass in favor of STEM disciplines in particular. A review of the projects reveals how much in reality the European school programs, and Italian ones in particular, are already equipped with all the antibodies (produced in response to and counteracting STEM illiteracy) necessary to face this challenge from a strictly cultural point of view. Rather, it is mainly the lack of adequate structures to prevent innovation in education and at the level of other countries.

Looking at the Italian research in mathematics education, for instance, as far as the cultural context is concerned, some of the antibodies have been developed within the paradigm of the research for innovation. The characteristic objects of investigation are the teaching and learning processes in mathematics, seen as complex dynamic systems, both in specific classroom contexts and in relation to the more general educational context (Arzarello & Bartolini Bussi, 1998). Innovative theoretical models and methodologies of working in the classroom, which may be used by teachers to guide their action in the classroom, were developed together with paradigmatic examples concerning improvement in the teaching of mathematics. From this perspective, throughout the educational process, teachers must deal in a balanced way with two essential intertwined aspects of mathematics: its global vision as a logically coherent and systematic body of knowledge and its instrumental nature as a tool for a quantitative understanding of reality. Without the former, mathematics becomes a series of recipes devoid of methods and justifications; deprived by the latter, it is reduced to a pure game with symbols without meanings. As a consequence, the school curriculum should lead students not only to the mastery of operational techniques but also to the ability to place these techniques in a theoretical framework that justifies them. Based on these assumptions, in 2001–2003, the curricular proposal "La Matematica per il Cittadino" (Mathematics for the Citizen) has been developed by the Italian Commission for Mathematics Teaching (UMI-CIIM). This development was possible thanks to the collaboration of academic researchers and school teachers and has become a basis for all subsequent guidelines for curricula and professional development projects for mathematics education developed by the Ministry of Education in the following years. One of the most important concepts brought to the fore by "La Matematica per il Cittadino" concerns the assumption that the mathematics education needs to be constructed through the interactions that develop during laboratorial kinds of work, in which apprentices learn by doing and seeing, communicating with each other and with teachers. From this perspective, mathematical skills are seen as a set of processes based both on mathematization as a modeling process of reality within an increasingly systematic theory and an exchange with others, as well as the interface between the individual and collective experience. Hence, the initiatives developed in Italy to improve school-based mathematics teaching and learning with respect to

---

[2] www.scinentix.eu

the STEM agenda are mainly carried out with the aim of providing students with operational concepts. These concepts are intended to be acquired in order to develop mastery of skills as "processes" structured into complex forms (reproduction, connection, reflection) and skills in the reading and production of mathematical texts. The latter, in particular, are considered important to avoid the split between verbal and symbolic aspects in the linguistic performance while doing mathematics.

In recent years, the Ministry of Education in Italy has also promoted a series of initiatives within the Europe Code Week, which aim to bring coding and digital literacy to everybody in a fun and engaging way[3]. According to the project, the basic assumption is that "Learning to code helps us to make sense of the rapidly changing world around us, expand our understanding of how technology works, and develop skills and capabilities in order to explore new ideas and innovate." The experimentation with coding, however, goes on sporadically, here and there, above all thanks to the enthusiasm and stubbornness of the teachers who believe in it. Anyway, a total of 16,336 classes were involved in 2015 (55% of those at the primary, 27% at the lower secondary level, and 15% at the upper secondary school), while Italy closed 2018 with more than 20,000 coding events on the Code Week map, more than those organized around the rest of Europe. Thanks to these activities, the Ministry of Education discovered that coding does not only appeal to computer science and mathematics teachers. The 2015 statistics say that the approach was multidisciplinary, with the participation of teachers of humanities (28%), sciences (22%), history (12%), and art (6%). Indeed, breaking down complex problems into smaller ones (decomposition), recognizing patterns (pattern recognition), identifying relevant details for solving a problem (abstraction), and setting out the rules or instructions to follow in order to achieve a desired outcome (algorithm design) are all computational thinking skills that can be taught across different disciplines, for instance, as Miles Berry[4] points out, in mathematics (figuring out the rules for factoring second-order polynomials), literature (breaking down the analysis of a poem into analysis of meter, rhyme, and structure), languages (finding patterns in the ending letters of a verb that affect its spelling as tense changes), and many others. Furthermore, this type of activity, carried out outside of school time, breaks the traditional classroom practices and encourages both students and teachers to interact and collaborate with each other.

At the same time, in 2015, to set up a comprehensive innovation strategy across Italy's school system and to bring it into the digital age, the Ministry of Education launched the Italian National Plan for Digital Education (Piano Nazionale Scuola Digitale or PNSD[5]). It answered the call for a long-term vision for education in the digital age directly linked to the challenges that all of society faces in applying and promoting life-long and life-wide learning, in both formal and non-formal contexts. Within this plan, in particular, it has been recognized that teachers and school staff

---

[3] https://codeweek.eu

[4] https://codeweek.eu/training/computational-thinking-and-problem-solving

[5] http://www.istruzione.it/scuola_digitale/allegati/2016/pnsd_en.pdf

would have to be placed in the right conditions to act as facilitators of innovative learning paths based on more familiar content for their students. They must be equipped for all the changes required by modernity and must be put in a position to live through and not defy innovation. Teacher training, as a consequence, must focus on educational innovation, taking into account digital technologies as supports for the realization of new educational paradigms and operational planning of learning activities. Moreover, if the contributions of the most innovative teachers serve to create the standards through which to organize training and, through certain and important resources, make it spread throughout the system, it is necessary to overcome the challenge of ushering all teachers into the new methodological paradigms.

To conclude this overview, I would stress that, despite the presence of possible antibodies on which we can rely, the era of change reveals itself with new challenges and new tools with which we meet them. For this reason, in order to investigate the role and professional expectations of STEM teachers and the advancement in twenty-first-century schools teaching, we need to reflect on some important aspects. For example, we should focus on how to support teacher-leaders as co-creators of professional development opportunities, create opportunities for teachers to work within novel student-centered and technology-rich environments, address teacher education needs in view of the growing demands from teachers, and bridge the disconnection between educational research and practice.

These are the aims that this book attempts to fulfill, and, in my view, it does so extremely well.

The book makes an original contribution to the field of teacher education in the era of change and discusses ways to unleash the potential of technology to support teacher education, teaching practices, and teacher professional development in STEM disciplines. Even if it comes from an Israeli-Canadian workshop held in Israel in 2018, the critical reflections it proposes go far beyond the results of the presented research studies. For this reason, it is going to be of interest for an international audience. In particular, the effective structure that editors have given to the book allows the reader, especially thanks to the discussion chapters, to have a broader and global perspective, which crosses any geographical boundaries. The book allows the reader to get an in-depth but global insight into possibilities and challenges of technology to support teacher education, teaching practices, and professional development in STEM disciplines in the twenty-first-century schools.

In my view, the strongest aspect of this work lies in the way the reader is guided to examine theory and practice in STEM teacher education, focusing on the professional development of teachers and on the teaching advancement in the twenty-first century.

From the first section, the empowerment of teachers by expanding their roles is advocated by the description of two projects, one developed in Canada and another in Israel. Moreover, the following discussion chapter brings to the fore general aspects, which do not depend on the two particular countries, but cross geographical boundaries.

The contributions in the second section aim to present two new perspectives: the first concerns professional learning communities of science teachers and the second provides a reflection on the relationship between technology and mathematics. Both these themes, of professional development and of the role of technology, discussed by the plenary speakers of the workshop, will be analyzed in depth throughout the next two sections of the book.

Teachers' professional learning communities supporting education reforms in STEM disciplines are the focus of the third section. Here, in particular, readers can take an in-depth journey into three different studies concerning Israeli chemistry, computer science, and physics teachers' professional development programs. The following discussion chapter adds to the analyses of the Israeli experiences a discussion on the research findings and insights from Canada and elsewhere, regarding the professional development practices for mathematics. Important differences among the cases, but also common themes, which cross disciplinary boundaries, are brought to the fore using the three conceptions of teacher learning defined by Cochran-Smith and Lytle (1999): knowledge for practice, knowledge of practice, and knowledge as practice.

The fourth section goes back to the other theme in the second section: the role of digital technologies in teaching and learning. The three contributions in this section explore emergent STEM teaching possibilities in the era of educational technologies, providing complementary examinations of the role of teachers in the productive integration of ICT into schools and its implications for teacher education. The following discussion chapter implicitly acknowledges that the availability of ICT and its use in teaching has drastically changed not only the nature of the tasks and learning activities students are engaged in but also the cognitive activity of the learners. Consequently, teachers should be continuously empowered to enhance their pivotal role in students' learning.

The last section of the book focuses on teachers' knowledge for successful teaching. Again, the readers are accompanied to reflect on this aspect through two chapters which, describing research into teachers' teaching in innovative student-centered and technology-rich learning environments, provide an opportunity to shed light on teachers' new roles, on the potential of technology to transform learning and teaching, and on the complexity of the milieus that the teachers work within. The final discussion chapter, indeed, elaborates on the crosscutting themes in these two chapters, discussing the fruitful relationship between research and practice that both projects demonstrate and the innovative nature of the described pedagogies. It also underlines the important role technology plays in facilitating transformative change, in sustaining a different classroom learning culture, and discusses the new roles of the teachers and the complex knowledge and dispositions they have to develop when aiming to maximize their students' learning.

To sum up, I would suggest this book to policy makers and STEM teacher educators, as it offers interesting theoretical considerations and practical suggestions in order to break the vicious circle of reforms. The book sheds light on supporting STEM teachers on a lifelong path of professional learning, empowering teachers with leadership and research skills, and unleashing the potential of technology to support teacher education, teaching practices, and the professional development of STEM teachers. The contributions, indeed, are informed by the latest research findings, current pedagogical trends and practices, and ways in which teacher education and the professional development of STEM educators respond to the challenges and the growing expectations of twenty-first-century schools.

Moreover, the book is also going to be of interest to educational researchers, students and post-graduate students in education, and STEM teachers, as the chapters cover a range of projects (from classroom-based to national initiatives), research methods (from action research and mixed methods to conceptual analyses), and technology applications (from social media and robotics to subject-based educational software).

Bari, Italy Eleonora Faggiano

References

Arzarello, F., & Bartolini Bussi, M. (1998). Italian trends of research in mathematics education: A national case study in the international perspective. In J. Kilpatrick & A. Sierpinska (Eds.), *Mathematics education as a research DOMAIN: A Search for identity* (pp. 243–262). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Cochran-Smith, M., & Lytle, S. L. (2009). *Inquiry as stance: Practitioner research for the next generation.* New York, NY: Teachers College Press.

Eurydice. (2011). *Science education in Europe: National policies, practices and research.* Brussels, Belgium: European Commission.

Marginson, S., Tytler, R., Freeman, B., & Roberts, K. (2013). *STEM: Country comparisons.* Final report for the Australian Council of Learned Academies, Melbourne, Vic.

OECD. (2013). *PISA 2012 assessment and analytical framework: Mathematics, reading, science, problem solving and financial literacy*. OECD Publishing. Retrieved from http://www.oecd.org/pisa/pisaproducts/PISA%202012%20framework%20e-book_final.pdf

Tytler, R., Swanson, D. M., & Appelbaum, P. (2015). Subject matters of science, technology, engineering, and mathematics. In M. F. He, B. D. Schultz, & W. H. Schubert (Eds.), *The Sage guide to curriculum in education* (pp. 27–35). Thousand Oaks, CA: Sage.

Contents

Introduction: STEM Teachers and Teaching in the Era of Change 1
Yifat Ben-David Kolikant, Dragana Martinovic, and Marina Milner-Bolotin

Part I Expanding Teachers' Roles: Empowerment of Teachers

Teacher Knowledge in the Era of Change 19
Dragana Martinovic and Heidi Horn-Olivito

Mathematics Teachers Edit Textbooks: Opportunities and Challenges 37
Ruhama Even

Discussion: Teacher Learning in Community: Premises, Promises and Challenges 53
Lily Orland-Barak

Part II New Perspectives in Teaching Science and Mathematics: Israeli and Canadian Perspectives

Professional Learning Communities of Science Teachers: Theoretical and Practical Perspectives 65
Bat-Sheva Eylon, Zahava Scherz, and Esther Bagno

On Teaching and Learning Mathematics – Technologies 91
Nathalie Sinclair

Part III Teacher Professional Development in the Era of Change

A Sense of Community in a Professional Learning Community of Chemistry Teachers: A Study of an Online Platform for Group Communication 111
Ruth Waldman and Ron Blonder

From Practice to Practical: Computer Science Teachers Teaching Teachers 141
Ofra Brandes, Yifat Ben-David Kolikant, and Catriel Beeri

Motivators, Contributors, and Inhibitors to Physics Teacher-Leaders' Professional Development in a Program of Professional Learning Communities 159
Smadar Levy, Esther Bagno, Hana Berger, and Bat-Sheva Eylon

Discussion: Teacher Professional Development in the Era of Change 185
Dragana Martinovic and Marina Milner-Bolotin

Part IV Emergent STEM Teaching Possibilities in the Era of Educational Technologies

Deliberate Pedagogical Thinking with Technology in STEM Teacher Education 201
Marina Milner-Bolotin

Teaching Mathematics in the Digital Era: Standards and Beyond 221
Michal Tabach and Jana Trgalová

Technology in Mathematics Teacher Education on Trust and Pitfalls 243
Rina Zazkis

Emergent STEM Teaching Possibilities in an Era of Educational Technologies 261
Shulamit Kapon

Part V Teachers' Knowledge for Successful Twenty-First Century Teaching

Issues of Teaching in a New Technology-Rich Environment: Investigating the Case of New Brunswick (Canada) School Makerspaces 273
Viktor Freiman

The Influence of teacher's Orchestration Using a Novel System for Advancing Group Learning on Students' Conceptual Learning – The Case of a Geometry Lesson 293
Naomi Prusak, Osama Swidan, and Baruch Schwarz

Discussion: Creating a New World –Teachers' Work in Innovative Educational Environments 313
Yifat Ben-David Kolikant

Index 321

About the Editors

Yifat Ben-David Kolikant is an Associate Professor in the Seymor Fox School of Education, Hebrew University of Jerusalem. Her academic work is devoted to theorizing learning, teaching, and schooling in the age of globalization and digitalism, an age characterized by the ubiquity of digital technology, an information explosion, pluralism, and rapid changes. Over the past few years, she has dealt with two core questions: (a) How does digital technology influence schooling and (b) how can effective teaching environments be characterized? In recent years she has been involved in several studies aimed at understanding and enhancing in-service teacher learning under conditions of dramatic curricular and policy changes, and the role that ICT plays and should play in it. Prof. Ben-David Kolikant holds a Ph.D. degree in science teaching from the Weizmann Institute of Science, received in 2002.

Dragana Martinovic is a Professor of Mathematics Education at University of Windsor, where she leads the Human Development Technologies Research Group. Dragana is a Fellow of the Fields Institute for Research in Mathematical Sciences and a Co-Director of the Fields Centre for Mathematics Education. She is a recipient of the Excellence in Mentoring Award at University of Windsor. In her research, Dr. Martinovic explores ways in which technology can improve teaching and learning outcomes, and the digital literacy skills needed for a successful learner and worker of the twenty-first century. She is dedicated to supporting teacher-led research and providing opportunities for all involved in education to collaboratively work towards increasing student engagement, success, and love for learning mathematics. Dragana is on the Executive for the Mathematics Knowledge Network, hosted by the Fields Centre for Mathematics Education. She co-chairs the Mathematics Leadership Community of Practice (since 2016) and the *Fields Cognitive Science Network for Empirical Study of Mathematics and How it is Learned*, and is a founding and current co-editor of the Springer book series, *Mathematics Education in the Digital Era*.

Marina Milner-Bolotin is an Associate Professor in science education in the Faculty of Education at the University of British Columbia, Vancouver, Canada. She holds a M.Sc. in theoretical physics from the Kharkov National University in Ukraine. She also holds M.A. and Ph.D. degrees in mathematics and science education from the University of Texas at Austin in 2001. At UT Austin, she investigated how project based instruction in physics courses for future elementary teachers affected their interest in science and their ability to do and teach science. She specializes in science and mathematics education and science outreach. She studies how technology can be used in teacher education to prepare mathematics and science teachers who will be able to engage twenty-first century students in meaningful learning. Her work has appeared in international peer-reviewed research journals, scientific books, conference proceedings, seminars, and workshops. Since 1993, she has been teaching science and mathematics in Israel, USA, China, and Canada to elementary students to university undergraduates in science programs, and to pre-service and in-service teachers. She has led many professional development activities for science in-service and pre-service teachers and university faculty. She is an author of an introductory physics textbook used by thousands of students. Before joining UBC, she was faculty member at Ryerson University in Toronto, Ontario. She has received numerous research and teaching awards and served on the Executive Board of Canadian and International science education associations. To learn more about her research and publications, visit her web site at: http://blogs.ubc.ca/mmilner/.

Introduction: STEM Teachers and Teaching in the Era of Change

Yifat Ben-David Kolikant, Dragana Martinovic, and Marina Milner-Bolotin

1 Why This Book?

This book is an outcome of the Israeli-Canadian Workshop entitled, *Teachers and Teaching in the Era of Change*, conducted in 2018 at the Hebrew University of Jerusalem. Compared to the usual international conferences of educators which tend to tackle too many issues simultaneously while having few opportunities to collaborate in examining these issues in depth, this workshop provided us with such an opportunity.

Informed by the latest research findings, the authors whose contributions are included in this edited book present current pedagogical trends and practices in public education, teacher education, and professional development of STEM (science, technology, engineering, and mathematics) educators. The chapters are organized into five parts, to present to our readers—educational researchers, policy makers, and graduate students in education—the distinct themes that the authors aimed to address. While all but one contributors come from Canada or Israel, they are all internationally acclaimed scholars whose research findings cannot be contained within any one geographical domain. This is because the challenges of teaching in the twenty-first century are not unique to Canada or Israel. Despite the vastly different sizes of our countries and different structures of teacher education and professional development programmes, we found that the STEM teachers in Canada and Israel face similar ordeals. While both countries are high-ranked on the

---

Y. Ben-David Kolikant (✉)
Seymour Fox School of Education, Hebrew University of Jerusalem, Jerusalem, Israel
e-mail: Yifat.Kolikant@mail.huji.ac.il

D. Martinovic
Faculty of Education, University of Windsor, Windsor, ON, Canada

M. Milner-Bolotin
Department of Curriculum and Pedagogy, Faculty of Education,
University of British Columbia, Vancouver, BC, Canada
e-mail: marina.milner-bolotin@ubc.ca

Y. Ben-David Kolikant et al. (eds.), *STEM Teachers and Teaching in the Digital Era*, https://doi.org/10.1007/978-3-030-29396-3_1

scale of economic development, their educational, political, demographic, geographic, and social contexts differ. In Canada, every province has its own jurisdiction over education—Provincial Ministry of Education, while in Israel, there is only one Ministry of Education for the entire country. Although the governments of both countries emphasize STEM education, their approaches to teacher education and professional development are distinct and thus provide for interesting comparisons.

Since educators in most countries share similar challenges, this book contributes to the general agenda by discussing ways in which to break the vicious circle of educational reforms, empower teachers with leadership and research skills, and unleash the potential of technology to support teacher education, teaching practices, and professional development of teachers from STEM fields.

Our collaboration within the editorial team and with authors allowed us to address the following four questions:

1. How to empower teachers to become active participants in educational decision- making?
2. How to break the vicious circle of educational reforms and keep abreast with drastic (not always adequately supported) curriculum, technology, and pedagogy changes, in favour of life-long teacher education and meaningful professional development?
3. How to bridge educational research, practice, and decision making?
4. How to prepare new and support practising teachers, who will be ready to educate the twenty-first century citizens?

We started this project from the realization that both the school education and teacher education systems are slow to change. In order to see *what* could be done to alter them and *how*, we needed to pause and reflect on what is going on within and outside of them—thus birthing this book through our collective effort.

2 Teaching in an Era of Change

Since the Industrial Revolution, schools have been preparing students with basic workplace skills by equipping them with a certain body of information, deemed both important and canonical. Nowadays, the expectations are shifting—the students educated today will function as adults in a rapidly changing world, work under the conditions of uncertainty, deal with the exponentially increasing amount of information, and become familiar (or even master) new technologies, new mediums through which they work, collaborate, and communicate. Knowledge and knowledge-oriented practices are assuming greater importance than ever before (Drucker, 1993; Välimaa & Hoffman, 2008). Furthermore, owing to trends of globalization and digitalization, tomorrow's adults will compete over jobs with millions of other people worldwide. These changing expectations prompt educators, parents, business leaders, and policymakers to express their ever-growing concerns that education institutions too often fail to prepare students for the demands of the twenty-first century (Bridich, 2015; Center for Education Reform, 2018). Consequently, many states are attempting to change their schools and adapt them to the twenty-first century demands (Griffin, McGaw, & Care, 2012; Law, Pelgrum, & Plomp, 2008; Mioduser, Nachmias, & Forkosh-Baruch, 2008; Pellegrino & Hilton, 2012). The problem is that although teachers are key for success of any reform, they have rarely had a chance to acquire the required twenty-first century skills as students or become comfortable with them through teacher education (Brandes, Ben-David Kolikant, and Beeri in this book; Martinovic & Zhang, 2012; Milner-Bolotin, 2016a; Milner-Bolotin, 2018).

Hargreaves (2004) asserts that disappointment with reforms (i.e., attempts for change) arises not just because of the unwanted imposition of reform demands, but also because of the cumulative effects of their repetitive, contradictory, and often evanescent nature. He suggests that one of the key factors that shape and drive educators' emotions in the context of change is the extent to which it is inclusive "of teachers' purposes, respectful of their priorities and sensitive to their working and implementation conditions" (p. 301). Such inclusive change and reform processes engage teachers' knowledge and commitment; teachers exercise their own professional judgment in the change process. Guided by their new knowledge of the best practices and techniques, teachers' professional involvement in school improvement is increased, thus making such change and reform "built to last" (p. 306). However, implementing the reform that engages teachers' knowledge and commitment is not easy. Therefore sharing successful experiences of how it can be done in an international context is especially valuable. This is one of the contributions this book has to offer.

3 New Skills for the New Century

Today's society demands from schools to nurture knowledge creation and life-long learning skills. Bereiter and Scardamalia (2003) eloquently challenge schools "to turn out people who, in addition to being proficient in [the basic academic skill areas of reading, writing, and elementary mathematics], will be prepared to learn new things, collaborate in the solution of novel problems, and produce innovations in areas that presently may not even exist" (p. 56). Many terms have been used extensively to try to articulate this range of skills, such as the twenty-first century skills, life-long learning skills, twenty-first century competencies, twenty-first century learning and innovation, and so forth. Attempts have been made to define the competencies, abilities, and dispositions one needs in order to prosper in tomorrow's world (Griffin et al., 2012; Pellegrino & Hilton, 2012).

In their review, Nir, Ben-David, Bogler, Inbar, and Zohar (2016) classified skills for the new century into four main domains: (meta)cognitive, inter-personal, intra-personal, and technological. Skills in the cognitive domain span the learner's ability to construct meaningful and in-depth knowledge, and to apply it creatively in new situations and contexts. Important cognitive attributes include metacognitive awareness and self-directed learning. The inter-personal domain covers one's ability to engage with others, such as through teamwork, leadership, and cooperation. The intra-personal domain concerns one's response to problems and challenges, such as intellectual openness, self-regulation, and managing emotions. Finally, the technological domain relates to one being literate with respect to information and communication technologies (ICTs); the aspect of special importance as even occupations that previously had little or nothing to do with ICT are nowadays under pressure to integrate technology into their daily activities (Martinovic & Freiman, 2016). Cultivating graduates with such knowledge and skills requires schools and teachers to become "used to change," as one "younger teacher who identified herself as Generation X" in Hargreaves study stated (Hargreaves, 2004 p. 295).

4 Schools for the New Century: Highlighting Teacher and Technology Roles

Missing in today's education, are the so-called "disruptive pedagogies" (Hedberg, 2011) that can both adapt to continual technological change, and involve students as co-creators of knowledge and producers of educational experiences (DeSchryver, Leahy, Koehler, & Wolf, 2013; Lindroth & Bergquist, 2010). Such pedagogies are progressive as they engage and empower the learners:

> If students live in a culture that digitizes and educates them through a screen, they require an education that empowers them in that sphere, teaches them that language, and offers new opportunities of human connectivity … In its evolution from passive consumption to critical production — from the cult of the expert to a culture of collaboration — the critical and digital classroom emerges as a site of intellectual and moral agency. (Rorabaugh, 2012, para. 7).

For generating and implementing a pedagogical transformative change, teachers are essential (Barber & Mourshed, 2007; Darling-Hammond et al., 2017). Barber and Mourshed (2007) examined 25 different educational systems around the world, including the 10 best performers (e.g., Singapore and Finland), only to find that well-educated and highly motivated teachers are at the core of these successful systems. The researchers concluded that:

> (1) The quality of an education system cannot exceed the quality of its teachers, (2) the only way to improve outcomes is to improve instruction and, (3) achieving universally high outcomes is only possible by putting in place mechanisms to ensure that schools deliver high-quality instruction to every child. (Barber & Mourshed, 2007, p. 40)

While revealing, such claims put enormous pressure on teachers, who need to adapt their pedagogy to the twenty-first century learning, to prepare students for continuous and self-regulated life-long learning, to help them become able and willing to collaborate with others, and also well-informed and well-networked citizens. Teachers too need to espouse life-long learning skills and dispositions. In a rapidly changing world, they are frequently asked to teach contents they are not very familiar with, or even “unlearn” ideas they were raised on. Also, they may have never experienced technology-rich pedagogies, neither as students nor as teachers in the professional development programs (Milner-Bolotin, Fisher, & MacDonald, 2013).

Technology plays a major role in schooling today. Even in schools with low or limited use of it, metaphorically, technology has entered through the back door (Ben-David Kolikant, 2010, 2012). For example, when giving homework assignments, teachers should take into account that students may utilize the Internet, which might lessen and alter the intellectual efforts required (e.g., by searching for prepared essays or problem solutions on the web). Often, educators experience difficulties when teaching and attribute them to lasting negative cognitive, behavioral, and social effects of students’ life with technology (Ben-David Kolikant, 2019). Even the voices from media and academics are split between those with pessimistic versus optimistic opinions about the effects of ICTs on young people (Livingstone, 2008). Optimists, for example, see in ICTs opportunities for “self-expression, sociability, community engagement, creativity, and new literacies” while pessimists consider “social networking as time-wasting [and use of other ICTs in schooling as] taking shortcuts, cheating, [that] may hinder development of study skills” (Martinovic, Freiman, Lekule, & Yang, 2018 p. 2315). But, regardless of their stance, all notice the transformational role of technology in both students’ and educators’ lives. Then again, we still have to see more evidence that technology is appropriately and widely used in formal education. Maybe if educators better understood the connections between the STEM concepts and the learners and tools (technologies) (see Sinclair in this book; Ben-David Kolikant in this book), they would feel more propelled to use them in their classes?

5 Educating and Supporting the Twenty-First Century Teachers

What we previously stated in this chapter point to key challenges in this century—to properly mentor and support teachers who might have been educated traditionally, and to help sustain their ability and will to remain in a life-long learning career that employs novel pedagogies and emerging technologies. Teachers in the STEM fields are particularly stressed as their disciplines are growing exponentially and curricula are continuously changing (British Columbia Ministry of Education, 2015; Ontario Ministry of Education, 2014).

How to educate teachers who will be ready for such and other twenty-first century challenges? How to sustain and support the life-long learning they need? This will clearly require a major change in teacher education programmes, and especially in STEM education, as these fields are at the forefront of the twenty-first century technological revolution.

Darling-Hammond (2009) is one among many researchers who suggests that teachers' professionalism is the key for sustaining the required change. She envisions empowering autonomous teachers with strong professional knowledge and a supportive peer network; teachers authorized and capable of making sound pedagogical decisions and adaptable to new situations and requirements. Yet, what would sustain these peer networks, knowing that teachers are extremely busy and have little time to reach out to colleagues in their own school? How to support teachers in acquiring the knowledge needed for integrating technology to support student learning? How to support teachers in making autonomous decisions based on sound research evidence and what is known about how students learn?

While the world has become more connected than ever before, many STEM teachers, especially the ones who teach in smaller and geographically remote schools and school districts often feel overwhelmed, disconnected and disempowered (Bobis, 2007; Bogler & Somech, 2004; Darling-Hammond et al., 2017; Ben-David Kolikant, 2019). To overcome the sense of isolation and adapt to change, teachers need to find ways to cross the boundaries of individual, geographical, and institutional settings (Martinovic et al., 2017). Some of them may get involved in research and professional development projects run by universities, or may engage in informal, organizational, or regional professional learning communities (PLCs) and communities of practice (CoPs). Indeed, most contributions to this book describe opportunities, challenges, and outcomes of collaborations between professionals in different roles (e.g., teachers, administrators, content experts, publishers, policy makers, and researchers), contributing significantly to theoretical and practical applications of education research, policy, and praxis.

6 The Uniqueness of Teaching STEM Disciplines

Educational change at any level is never easy (Mazur, 1997; Miller, Fairweather, Slakey, Smith, & King, 2017; Wieman, 2012). It is especially difficult to prepare the next generation of teachers from STEM disciplines, as these disciplines are fundamental to future innovations and vital to solving the competing national economic agendas in the global twenty-first century context (Council of Canadian Academies, 2015).

The UK's government "Plan for Growth," was a plan for action for the country to "earn its way in the modern world" (BIS, 2011, p. 3). The Plan for Growth document outlined four overarching goals, one of which was to create a "more educated workforce that is the most flexible in Europe" (p. 5). This was to be accomplished, among else, by emphasizing STEM education, and revamping pre-service teacher education and in-service teachers' professional development to increase the number of computer science specialist teachers (Martinovic & Freiman, 2013).

In the report, "Rising above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future" (National Academy of Sciences [NAS], 2011), the top recommendation was to “Increase America’s talent pool by vastly improving K–12 science and mathematics education” (p. 5). The Report suggested that this be done through: (a) “annually [recruiting] 10,000 science and mathematics teachers”; and (b) “[strengthening] the skills of 250,000 [current] teachers through training and education programs” (p. 5). While teacher education gives them a good head start, professional development is essential for teachers to remain current in their professional knowledge.

The Council of Canadian Academies’ (2015) report suggests that: “STEM skills [e.g., mathematics, computational facility, reasoning, and problem solving] are necessary for many types of innovation, as well as productivity and growth, but they are not sufficient on their own. Other skills such as leadership, creativity, adaptability, and entrepreneurial ability may be required to maximize the impact of STEM skills” (p. 17).

And yet, despite the efforts that many countries around the world have put into STEM education reforms aimed at including a stronger STEM-related content and technology-rich, student-centered pedagogies, traditional information-focused and teacher-centered practices are still prevalent (BSCS, 2008; Feder, 2010; Nir et al., 2016). Too often, the pedagogical practices teachers perceive as innovative—as they rely heavily on modern technologies—actually support an information-focused agenda and teacher-centered pedagogies that these teachers have experienced in their own education (Ben-David Kolikant, 2019). Use of novel technologies should not be the sole purpose of pedagogical innovations, student learning should (Fraillon, Ainley, Schulz, Friedman, & Gebhardt, 2014; Milner-Bolotin, 2016b). Multiple contributions to this book address ways in which technology empowers teachers to learn and teach differently and better (e.g., Prusak, Swidan and Schwarz; Milner-Bolotin). We have also dedicated a part of this book to possibilities of enhancing STEM education through use of technologies, and also have three position chapters dedicated to this issue (i.e., Sinclair; Tabach and Trgalová; Zazkis).

7 Potential of Technology to Empower Teachers

Technology has a potential to empower teachers in this era of change, but as it has been widely documented this will not happen just by introducing the technology into the STEM classrooms (Auerbach, Higgins, Brickman, Andrews, & Labov, 2018; Martinovic & Manizade, 2017; Martinovic & Zhang, 2012; Zhang & Martinovic, 2008). Exploring how this can be done and challenging us to think outside of “the digital black box,” Tondeur et al. (2013, p. 436) conclude that “a supportive, blame-free environment that encourages and facilitates professional dialogue, and provides opportunities to extend and experiment with new practice can promote and further advance teaching and learning with technology” (p. 446).

Results of the 2011 EU-wide survey of teachers and students suggest that effective professional development is needed to increase the number of “digitally confident and positive [towards digital technologies]” teachers (Wastiau et al., 2013,

p. 19). Indeed, to overcome the limitations of distance, time, cost, and lack of immediate access to expertise, an increasing number of professional learning initiatives utilize social media, as was the case in Ontario where the networked mathematics teachers used on-line radio program, project Website, and Twitter to learn within a community of peers and experts (Donsky & Martinovic, 2018).

For the three of us, as editors of this book and scholars in the area of learning technologies, this topic also has an emotional value. Chapters in this book encompass projects and research questions that relate to the role of technology in both pre-service and in-service programs, thus also contributing to this area of inquiry.

8 Structure of the Book

The contributions to this book are organized into five parts. Following the organization of the workshop, each part contains two-three topic chapters and a discussion chapter. In the further text, we introduce their content.

8.1 Part I: Expanding Teachers' Roles: Empowerment

In this part, we have three chapters that directly advocate for empowerment of teachers by expanding their roles, so that they encompass research and leadership (Martinovic & Horn-Olivito) and curriculum development (Even).

In Chap. 2, Teacher Knowledge in the Era of Change, Dragana Martinovic and Heidi Horn-Olivito, make a case for educators working together, schools becoming centres of inquiry, and teachers becoming recognized as researchers and leaders. They describe a longitudinal collaboration between one Ontario school board and a university, which was a stepping-stone for these institutions co-leading a province-wide Mathematics Leadership Community of Practice as part of one of the latest reforms in mathematics education.

In Chap. 3, Teachers Editing Textbooks: Opportunities and Challenges, Ruhama Even discusses the project in which the Israeli mathematics teachers embarked to edit textbook materials for their classes. While Even uncovers the potential shortcomings of the teachers' textbook editing (e.g., divergence from the intended curriculum and the didactically problematic presentation of mathematical ideas), she finds the potential of this approach in transforming the conventional connections of teachers with textbook authors and with mathematicians.

In her Discussion Chap. 4, Lili Orland-Barak, reflects on the two chapters in Part I and writes about the premises, promises and challenges of teacher learning and acting in a community of practice. Orland-Barak finds the mediating role of the mentor/facilitator crucial for establishing the quality of professional discourse in a community—in using the right amount of support and challenge, connecting different kinds of knowledge, and challenging teachers to critically explore their taken-for-granted assumptions about teaching and learning. She also offers some future lines of investigation related to educators' learning in a community.

8.2 Part II: Expanding Teachers' Roles: Israeli and Canadian Perspectives

This part contains two chapters written by the workshop plenary speakers. A team of Israeli scholars talked about their project and gave a wider overview of professional development of science educators in Israel, while a Canadian scholar, Nathalie Sinclair, called for a different conceptualization of role of technology in teaching and learning mathematics.

Chapter 5 comes from Bat-Sheva Eylon, Zahava Scherz, and Esther Bagno, the Israeli team of educators who discuss theoretical and practical perspectives of the middle school science and physics high school professional learning communities (PLCs). While initially organized in a top-down fashion, the PLCs evolved into a network with more symmetric sharing of responsibilities. The researchers concluded that the PLCs in which practitioners collaborate with academics present a useful and efficient model for organizing professional development of teachers.

In Chap. 6, Nathalie Sinclair explores the role of digital technologies in teaching and learning mathematics. After discussing ways in which existing theories of mathematics learning position technology in the teaching and learning process, she re-conceptualizes relation between technology and mathematics. Sinclair posits that "the transformational use of digital technologies will not be possible until we reckon adequately with the ways in which mathematics and tools are intertwined," and gives examples of technologies that engage users' heads and hands to help them develop alternative representations of mathematics concepts.

8.3 Part III: Developing Teacher Learning Communities in the Era of Change

In this part, we have three chapters, all written by Israeli authors, and a discussion chapter written by Canadian scholars.

In Chap. 7, Ruth Waldman and Ron Blonder discuss a PLC of Israeli chemistry teachers from the standpoint of a Sense of Community framework. In addition to meeting face-to-face, this PLC used an online tool, WhatsApp, to connect and exchange texts, pictures, and videos, and was successful in facilitating social relationships, personal connections, and a sense of belonging. Waldman and Blonder also identified some challenges, mainly in having off-track online conversations, and difficulty in deciphering if members are doing well, as well as explaining their inactivity. In all cases, proper facilitation of the PLC was fundamental for its success.

Chapter 8 written by Ofra Brandes, Yifat Ben-David Kolikant, and Catriel Beeri, examines the rules underlying the content- and pedagogy-based choices of lead computer science teachers while conducting professional development of their peers. In the context of a new Israeli reform of computer science curriculum, these teachers adapted the curriculum materials for their peers, so that they are more practical and less academic. Brandes, Ben-David Kolikant, and Beeri found that the primary motivation of lead teachers was to address the immediate needs of the participants' teaching practice and avoid their resistance to learning anything beyond this need.

In Chap. 9, Smadar Levy, Esther Bagno, Hana Berger, and Bat-Sheva Eylon discuss motivators, contributors, and inhibitors to high school physics teacher-leaders' professional development. The teacher-leaders participated in a PLC led by a team from the Weizmann Institute of Science in Rehovot, Israel, while they simultaneously lead regional PLCs of high-school Israeli physics teachers. Levy et al. found that each teacher-leader tried new instructional practices, based on different personal circumstances, views and priorities, and commitments to the PLC. The researchers made a case that more research is needed on the factors influencing the recruitment and retention of teacher-leaders, as well as the sustainability of PLCs.

In their Discussion Chap. 10, Dragana Martinovic and Marina Milner-Bolotin reflect on the three chapters in this part, as well as on the first chapter, Teacher knowledge in the Era of change, asking the following questions: What knowledge is valued by the practitioners? To what extent the centrally given PD for lead teachers become individualized and filtered in its delivery to peers in the field? In their analysis, Martinovic and Milner-Bolotin use the three conceptions of teacher learning defined by Cochran-Smith and Lytle (1999): knowledge-*for*-practice, knowledge-*of*-practice, and knowledge-*as*-practice.

8.4 Part IV: Emergent STEM Teaching Possibilities in the Era of Educational Technologies

Part IV contains three chapters, two from Canadian scholars and another from an international team (Israel/France) of scholars. An accompanying discussion chapter is written by an Israeli scholar.

In Chap. 11, Marina Milner-Bolotin writes about theory and practice of technology-enhanced STEM teacher education for twenty-first century. Building from Shulman's and Vygotsky's theoretical work, she introduces a new theoretical framework, Deliberate Pedagogical Thinking with Technology (DPTwT). This framework emphasizes the growth of teacher knowledge, as a result of collaboration with peers and more experienced colleagues. Milner-Bolotin "challenges teacher educators to consider how the modeling of technology-enhanced and research-based pedagogies in teacher education courses can help bridge educational research with educational practice."

Chapter 12, by Michal Tabach and Jana Trgalová, explores issues in integration of ICTs into teaching mathematics. The authors start by examining ICT standards for (mathematics) teachers in several OECD countries and in Australia, and then define a conceptual framework to capture various dimensions of teachers' professional knowledge and skills for using digital technology. Tabach and Trgalová conclude by inviting educators to develop more standards for teaching with ICT, such that would cover different age groups and school subjects.

In Chap. 13, Rina Zazkis analyzes drawbacks in understanding mathematical ideas associated with the use of digital technology. She examines examples of mathematics exercises done with different technologies, when the intermediate results or screen views are mathematically "incorrect or incomplete and therefore misleading, and argue for further attention to fidelity of technology in teacher education."

Chapter 13 by Rina Zazkis problematizes "a blind trust" with which the users often approach technology. Indeed, Goos, Galbraith, Renshaw, and Geiger (2000) described how teachers (and students) may utilize technology as a *master*, which creates both mathematical and pedagogical challenge. Zazkis highlights that mathematical fidelity, that is "the conformity of a technological tool with mathematical accuracy," needs to be uncovered during teacher education, and by extension in professional development of teacher. Failing to do so would open opportunities for false conclusions and misunderstanding of mathematical ideas associated with the use of digital technology.

Discussion Chapter 14 by Shulamit Kapon reflects on the chapters in this part and explores emergent STEM teaching possibilities in an era of educational technologies. Kapon uses the frameworks of distributed cognition, affordance, appropriation, and knowledge in pieces to argue that the views of authors in this part have important consequences for development of teacher education programs. She concludes that "the era of educational technologies presents a myriad of emergent STEM teaching possibilities for teachers, and teachers should be constantly empowered to enhance their pivotal role in students' learning."

8.5 Part V: Teachers' Knowledge for Successful Twenty-First Century Teaching

This part contains two chapters, one written by a Canadian scholar and the other by an Israeli team. Discussion chapter is written by an Israeli scholar.

In Chap. 15, Viktor Freiman investigates the case of New Brunswick's school makerspaces, a recent innovation in developing STEM-related skills in elementary and secondary school students. Freiman found that teachers who pioneered this new learning environment exhibited a particular mindset (e.g., ‘innovator’s mindset’, resilience when dealing with technology, and focus on inclusive yet challenging tasks), which led them to generate a novel learning environment (Ben-David Kolikant, in this book) and engage students in the twenty-first century learning.

In Chap. 16, Naomi Prusak, Osama Swidan, and Baruch Schwarz present teacher’s orchestration of students’ conceptual learning in the context of Virtual Math Teams. The System for Advancing Group Learning in Educational Technologies (SAGLET) technological tool allowed teachers to follow critical moments in the work of student groups, such as paths in solving geometry problems, being idle or unfocused, and needing technical help. Prusak et al. found that teachers could effectively multitask in a SAGLET environment—attend multiple student on-line discussions and intervene when needed. The researchers conclude that having a dedicated technology “is a promising direction towards the elaboration of new and sophisticated teaching practices.”

Discussion Chap. 17 by Yifat Ben-David Kolikant looks at the chapters from the point of creating novel, student-centred, technologically rich learning environments. Ben-David Kolikant asks about the teacher role in such an environment and the knowledge they need to develop in order to maximize students’ learning. She uses a framework of “intellectual partnership with technology” (Salomon et al. 1991), as she sees that students in both projects use technology as a thinking tool. To identify the type of learning in such an environment, Ben-David Kolikant uses a concept of bricolage, an idea that students in the new era learn differently, often through playful experimentation and creation of objects that they care about. Such environments ask that teachers teach differently, being mindful not to water down the learning to “hands-on minds-off” trial and error approach. In such an environment teachers need to multi-task, to provide for both individualized and group learning, to deal with different technologies, and to support “fruitful collaboration and creative knowledge creation” (ibid.) among students.

9 Overview of the Common Themes

As the workshop organizers and editors of this book we wanted to focus on the four main themes: (a) supporting teacher-leaders as co-creators of professional development opportunities; (b) creating opportunities for teachers to work within novel student-centred and technology-rich environments; (c) addressing teacher education needs in view of the growing demands from teachers; and (d) bridging the disconnect between educational research and practice. Our exemplary pool of authors addressed these themes, providing a rich and diverse outlook at learning and teaching of STEM subjects. The projects described in this book present a cautiously optimistic view at education in the era of frequent reforms. Because “[c]hange and emotion are inseparable” (Hargreaves, 2004 p. 287), we cannot but be emotional about the work that educators across the globe are doing, all with a same guiding thought of, “how to benefit our students." This book is a testament of such work, and we are indebted to our authors and all educators who participated in their studies for what they are trying to accomplish. Only by learning from each other, and exchanging ideas and experiences, we can hope to create a productive and fruitful environment for educating and supporting the twenty-first century teachers in the era of change.

Acknowledgements We acknowledge Halbert Centre for Canadian Studies at the Hebrew University of Jerusalem, for supporting a workshop entitled "Teachers and Teaching in the Era of Change," from which this book originated. Thanks to the Centre's support, in February 2018, we were able to bring together Israeli and Canadian educational researchers, teacher-educators, policy-makers, and secondary teachers who have been grappling with issues discussed in this book for a long time.

The goal of this 3-day Israeli-Canadian workshop was to establish collaboration between Israeli and Canadian educators and produce a book that will address our guiding questions. The workshop had 33 participants: 26 from Israel and 5 from Canada. All these individuals influenced what is presented in this book and some of them contributed chapters. We had two open plenary talks (by Canadian and Israeli speakers), and concluded the workshop with the session that allowed us to brainstorm and discuss how we can best disseminate the outcomes of the workshop and what areas might be fruitful for continuous collaboration.

References

Auerbach, A. J., Higgins, M., Brickman, P., Andrews, T. C., & Labov, J. (2018). Teacher knowledge for active-learning instruction: Expert–novice comparison reveals differences CBE. *Life Sciences Education, 17*, ar12.

Barber, M., & Mourshed, M. (2007). *How the world's best performing school systems come out on top*. London, UK: McKinsey & Company.

Ben-David Kolikant, Y. (2010). Digital natives, better learners? Students' beliefs about how the internet influenced their ability to learn. *Computers in Human Behavior, 26*, 1384–1391.

Ben-David Kolikant, Y. (2012). Using ICT for school purposes: Is there a student-school disconnect? *Computers & Education, 59*, 907–914.

Ben-David Kolikant, Y. B.-D. (2019). Adapting school to the 21st century: Educators' perspectives. *Technology Pedagogy and Education*, *28*(3), 287–299.

Bereiter, C., & Scardamalia, M. (2003). Learning to work creatively with knowledge. In E. De Corte, L. Verschaffel, N. Entwistle, & J. Van Merrienboer (Eds.), *Powerful learning environments: Unraveling basic components and dimensions* (pp. 55–68). Oxford, UK: Pergamon.

BIS. (2011). *The plan for growth*. HM Treasury's Department for Business Innovation and Skills. Retrieved from https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/221514/2011budget_growth.pdf

Bobis, J. (2007). Empowered to teach: A practice-based model of teacher education. In J. Watson & K. Beswick (Eds.),. Mathematics: Essential Research *Essential practice: Proceedings of the 30th annual conference of the mathematics education Group of Australasia* (pp. 61–70). Adelaide, Australia: MERGA.

Bogler, R., & Somech, A. (2004). Influence of teacher empowerment on teachers' organizational commitment, professional commitment and organizational citizenship behavior in schools. *Teaching and Teacher Education, 20*, 277–289.

Bridich, S. M. (2015). The invisible schism: Teachers' and administrators' differing perceptions of education reforms. *Education Policy Analysis Archives, 24*, 25.

British Columbia Ministry of Education. (2015). Building students success: BC's new curriculum. *BC Ministry of Education*. Retrieved from https://curriculum.gov.bc.ca/. 2018.

BSCS. (2008). *Scientists in science education: 1958–2008 innovation reform vision*. www.bscs.org. 2018.

Center for Education Reform. (2018). *A nation still at risk? Results from the latest NAEP recall the report from 35 years ago*. Retrieved from https://www.edreform.com/2018/04/a-nation-still-at-risk/

Cochran-Smith, M., & Lytle, S. L. (1999). Relationships of knowledge and practice: Teacher learning in communities. *Review of Research in Education, 24*, 249–305. https://doi.org/10.2307/1167272

Council of Canadian Academies. (2015). *Some assembly required: STEM skills and Canada's economic productivity/the expert panel on STEM skills for the future*. Ottawa, Canada: The Council of Canadian Academies.

Darling-Hammond, L. (2009). Teaching and the change wars: The professionalism hypothesis. In A. Hargreaves & M. Fullan (Eds.), *Change wars* (pp. 45–68). Bloomington, IN: Solution Tree.

Darling-Hammond, L., Burns, D., Campbell, C., Goodwin, L., Hammerness, K., Low, E. L., … Zeichner, K. M. (2017). *Empowered educators: How high-performing systems shape teaching quality around the world*. New York, NY/San Francisco, CA: Wiley/Jossey-Bass.

DeSchryver, M. D., Leahy, S. M., Koehler, M. J., & Wolf, L. G. (2013). The habits of mind necessary to generate new ways of teaching in a career of constant change. *TechTrends, 57*, 40–46.

Donsky, D., & Martinovic, D. (2018). The Math Pod - learning mathematics one podcast at a time. In C. Pike (Ed.), *Technology leader or leading technology. The CAP [Canadian Association of Principals] Journal: The Canadian Resource for School Based Leadership* (pp. 43–45).

Drucker, P. F. (1993). *Postcapitalist society*. New York, NY: HarperCollins Publishers.

Feder, T. (2010). Europe reflects on a decade of higher education reforms. *Physics Today, 63*, 24–27.

Fraillon, J., Ainley, J., Schulz, W., Friedman, T., & Gebhardt, E. (2014). *Preparing for life in a digital age: The IEA international computer and information literacy study international report*. Heidelberg, Germany: International Association for the Evaluation of Educational Achievement (IEA).

Goos, M., Galbraith, P., Renshaw, P., & Geiger, V. (2000). Reshaping teacher and student roles in technology rich classrooms. *Mathematics Education Research Journal, 12*(3), 303–320.

Griffin, P., McGaw, B., & Care, E. (2012). The changing role of education and schools. In P. Griffin, B. McGaw, & E. Care (Eds.), *Assessment and teaching of 21st century skills* (pp. 1–16). Dordrecht, The Netherlands: Springer.

Hargreaves, A. (2004). Inclusive and exclusive educational change: Emotional responses of teachers and implications for leadership. *School Leadership and Management, 24*(3), 287–309.

Hedberg, J. (2011). Towards a disruptive pedagogy: Changing classroom practice with technologies and digital content. *Educational Media International, 48*, 1–16.

Law, N., Pelgrum, W., & Plomp, T. (Eds.). (2008). *Pedagogy and ICT use in schools around the world: Findings from the IEA SITES 2006 study*. Hong Kong, China: Comparative Education Research Centre, Springer.

Lindroth, T., & Bergquist, M. (2010). Laptopers in an educational practice: Promoting the personal learning situation. *Computers & Education, 54*, 311–320.

Livingstone, S. (2008). Taking risky opportunities in youthful content creation: Teenagers use of social networking sites for intimacy, privacy and self-expression. *New Media & Society, 10*(3), 393–411.

Martinovic, D., & Freiman, V. (2013). *Digital skills development for future needs of the Canadian labour market*. Ottawa, Canada: Social Sciences and Humanities Research Council.

Martinovic, D., & Freiman, V. (2016). *Digital literacy and skills development: Results from a knowledge synthesis*. Paper presented at the digital intelligence 2016: International conference on digital intelligence, Montreal, QC, Canada, April 4–6.

Martinovic, D., Freiman, V., Lekule, C., & Yang, Y. (2018). In M. Khosrow-Pour (Ed.), *The roles of digital literacy in social life of youth* (The fourth edition of encyclopedia of information science and technology) (Vol. III, pp. 2314–2325). Hershey, PA: IGI Global.

Martinovic, D. & Manizade, A. G. (2017). Using grounded theory to extend existing PCK framework at the secondary level. Special Issue of the *Education Sciences*: Critical Issues in Mathematics Education 7: 1–17.

Martinovic, D., Ratković, S., Spencer, T., Grierson, A., Cantalini-Williams, M., & Landon, S. (2017). Engaged scholarship in action: The journey of the school board-university research exchange (SURE) network. *Engaged Scholar Journal: Community-Engaged Research, Teaching, and Learning, 3*(2), 39–57.

Martinovic, D., & Zhang, Z. (2012). Situating ICT in the teacher education program: Overcoming challenges, fulfilling expectations. *Teachers and Teacher Education, 28*(3), 461–469.

Mazur, E. (1997). Moving the mountain: Impediments to change. *The Physics Teacher, 35*, 1–4.

Miller, E. R., Fairweather, J. S., Slakey, L., Smith, T., & King, T. (2017). Catalyzing institutional transformation: Insights from the AAU STEM initiative. *Change, 49*, 36–45.

Milner-Bolotin, M. (2016a). Promoting deliberate pedagogical thinking with technology in physics teacher education: A teacher-educator's journey. In T. G. Ryan & K. A. McLeod (Eds.), *The physics educator: Tacit praxes and untold stories common ground and the learner* (pp. 112–141). Champaign, IL.

Milner-Bolotin, M. (2016b). Rethinking technology-enhanced physics teacher education: From theory to practice. *Canadian Journal of Science, Mathematics and Technology Education, 16*, 284–295.

Milner-Bolotin, M. (2018). Evidence-based research in STEM teacher education: From theory to practice. *Frontiers in Education: STEM Education, 14*(October).

Milner-Bolotin, M., Fisher, H., & MacDonald, A. (2013). Modeling active engagement pedagogy through classroom response systems in a physics teacher education course LUMAT. *International Journal on Math Science and Technology Education, 1*, 523–542.

Mioduser, D., Nachmias, R., & Forkosh-Baruch, A. (2008). New literacies for the knowledge society. In J. Knezek & J. Voogt (Eds.), *International handbook of information Technology in Education* (pp. 23–42). New York, NY: Springer.

National Academy of Sciences [NAS]. (2011). *Rising above the gathering storm: Energizing and employing America for a brighter economic future*. Washington, DC: National Academy of Sciences.

Nir, A., Ben-David, A., Bogler, R., Inbar, D., & Zohar, A. (2016). School autonomy and 21st century skills in the Israeli educational system: Discrepancies between the declarative and operational levels. *International Journal of Educational Management, 30*, 1231–1246.

Ontario Ministry of Education. (2014). *Achieving excellence: A renewed vision for education in Ontario*. Retrieved from http://www.edu.gov.on.ca/eng/about/renewedvision.pdf

Pellegrino, J. W., & Hilton, M. L. (Eds.). (2012). *Education for life and work: Developing transferable knowledge and skills in the 21st century*. Washington, DC: The National Academies Press.

Rorabaugh, P. (2012). *Occupy the digital: Critical pedagogy and new media*. Retrieved from http://hybridpedagogy.org/occupy-the-digital-critical-pedagogy-and-new-media/

Salomon, G., Perkins, D. N., & Globerson, T. (1991). Partners in cognition: Extending human intelligence with intelligent technologies. *Educational Researcher, 20*(3), 2–9.

Tondeur, J., Kershaw, L., Vanderlinde, R., & Braak, J. (2013). Getting inside the black box of technology integration in education: Teachers' stimulated recall of classroom observations. *Australasian Journal of Educational Technology, 29*, 434–449.

Välimaa, J., & Hoffman, D. (2008). Knowledge society discourse and higher education. *Higher Education, 56*, 265–285.

Wastiau, P., Blamire, R., Kearney, C., Quittre, V., Van de Gaer, E., & Monseur, C. (2013). The use of ICT in education: A survey of schools in Europe. *European Journal of Education, 48*, 11–27.

Wieman, C. E. (2012). Applying new research to improve science education. *Issues in Science and Technology, 29*(1), 25–32.

Zhang, Z., & Martinovic, D. (2008). ICT in teacher education: Examining needs, expectations and attitudes. *The Canadian Journal of Learning and Technology, 34*(2), 149–166.

Yifat Ben-David Kolikant is an Associate Professor in the Seymor Fox School of Education, Hebrew University of Jerusalem. Her academic work is devoted to theorizing learning, teaching, and schooling in the age of globalization and digitalism, an age characterized by the ubiquity of digital technology, an information explosion, pluralism, and rapid changes. Over the past few years, she has dealt with two core questions: (a) How does digital technology influence schooling and (b) how can effective teaching environments be characterized? In recent years she has been involved in several studies aimed at understanding and enhancing in-service teacher learning under conditions of dramatic curricular and policy changes, and the role that ICT plays and should play in it. Prof. Ben-David Kolikant holds a Ph.D. degree in science teaching from the Weizmann Institute of Science, received in 2002.

Dragana Martinovic is a Professor of Mathematics Education at University of Windsor, where she leads the Human Development Technologies Research Group. Dragana is a Fellow of the Fields Institute for Research in Mathematical Sciences and a Co-Director of the Fields Centre for Mathematics Education. She is a recipient of the Excellence in Mentoring Award at University of Windsor. In her research, Dr. Martinovic explores ways in which technology can improve teaching and learning outcomes, and the digital literacy skills needed for a successful learner and worker of the twenty-first century. She is dedicated to supporting teacher-led research and providing opportunities for all involved in education to collaboratively work towards increasing student engagement, success, and love for learning mathematics. Dragana is on the Executive for the Mathematics Knowledge Network, hosted by the Fields Centre for Mathematics Education. She co-chairs the Mathematics Leadership Community of Practice (since 2016) and the *Fields Cognitive Science Network for Empirical Study of Mathematics and How it is Learned*, and is a founding and current co-editor of the Springer book series, *Mathematics Education in the Digital Era*.

Marina Milner-Bolotin is an Associate Professor in science education in the Faculty of Education at the University of British Columbia, Vancouver, Canada. She holds a M.Sc. in theoretical physics from the Kharkov National University in Ukraine. She also holds M.A. and Ph.D. degrees in mathematics and science education from the University of Texas at Austin in 2001. At UT Austin, she investigated how project based instruction in physics courses for future elementary teachers affected their interest in science and their ability to do and teach science. She specializes in science and mathematics education and science outreach. She studies how technology can be used in teacher education to prepare mathematics and science teachers who will be able to engage twenty-first century students in meaningful learning. Her work has appeared in international peer-reviewed research journals, scientific books, conference proceedings, seminars, and workshops. Since 1993, she has been teaching science and mathematics in Israel, USA, China, and Canada to elementary students to university undergraduates in science programs, and to pre-service and in-service teachers. She has led many professional development activities for science in-service and pre-service teachers and university faculty. She is an author of an introductory physics textbook used by thousands of students. Before joining UBC, she was faculty member at Ryerson University in Toronto, Ontario. She has received numerous research and teaching awards and served on the Executive Board of Canadian and International science education associations. To learn more about her research and publications, visit her web site at: http://blogs.ubc.ca/mmilner/.

Part I
Expanding Teachers' Roles: Empowerment of Teachers

Teacher Knowledge in the Era of Change

Dragana Martinovic and Heidi Horn-Olivito

> [F]or teachers, enacting a new idea is not a matter of simple adoption but rather a matter of figuring out whether, when, and how to incorporate that new idea into an ongoing system of practice which is already satisfactory, and may also be largely habitual. (Kennedy, 2016, p. 955)

1 Introduction

Over the last few decades, philosophies that underpin education have changed in response to recent developmental, learning, and motivational theories suggesting that all children are capable learners and deserve optimal educational opportunities. Social pressures (e.g., to diversify programs and offerings, to improve instruction and outcomes; Cohen, Spillane, & Peurach, 2018) and educational technologies (e.g., computers, iPads, calculators, and technology-based learning systems and materials; Serdyukov, 2017), also called for change. As a result, education systems have experienced multiple reforms, which have greatly affected the role of teachers.

There are growing expectations from the general public and policy-makers that place increasing pressure on educators to be innovators (Hargreaves, 2003; Serdyukov, 2017) and to constantly learn (Kelly, 2004); to be connected and engaged in collaborative learning (Ferguson & Hirsch, 2014). Teachers are asked to be leaders—to "have the capacity to engage fully with the complexities of education and to be key actors in shaping and leading educational change" (Donaldson, 2010, p. 14); to facilitate school learning communities, strive for pedagogical excellence, and confront barriers in the school's culture and structures (Crowther, Ferguson, & Hann, 2009).

D. Martinovic (✉)
Faculty of Education, University of Windsor, Windsor, ON, Canada
e-mail: dragana@uwindsor.ca

H. Horn-Olivito
GECDSB, Windsor, ON, Canada
e-mail: Heidi.Horn-Olivito@publicboard.ca

Y. Ben-David Kolikant et al. (eds.), *STEM Teachers and Teaching in the Digital Era*, https://doi.org/10.1007/978-3-030-29396-3_2

The reach and role of an educator is immense and continuously changing. In order to flourish as a teacher in the era of change, one must develop a flexible set of learning skills, which can help in adaptation to an ever-changing workplace environment. One must position oneself as a learner—a paradigm shift that has significant implications.

One of the ways in which teachers can develop these flexible skills is through educators-led inquiry projects, in which teams of educators systematically examine their teaching practice using research techniques (Cameron, Kokis, & Ryerson, 2014). Indeed, we have found that exploration of one's own ideas, related to their own context, can provide conditions critical for developing leadership skills and influencing change. Although "the traditional top-down approach–where the teacher is positioned at the bottom of the 'knowledge funnel', being handed someone else's research-based 'best practices' to implement–is still firmly in place" (Martinovic et al., 2012, p. 400), through these projects, educators have an opportunity to develop research and leadership skills that inform system and school decisions. How can teachers see themselves as researchers and leaders? In this chapter we present our approach to addressing these issues in an attempt to contribute to "ideas about teacher learning… [and helping] teachers incorporate new ideas into their ongoing systems of practice" (Kennedy, 2016, p. 973).

When teachers develop their skills as leaders and innovators, they impact change across a system. We have seen many examples of this emerge from our inquiry work in schools (Martinovic, Winney, & Dabaja, 2017; Martinovic, Winney, & Knight, 2015). As teachers develop agency, they start challenging systemic norms and resetting these norms to align to a current context. For example, we supported several studies conducted by the school librarians who elicited collaborations with classroom teachers as a way to improve teachers' attitudes towards inquiry-based learning and to enhance students' information literacy skills. The school librarians made a case that their expertise is fundamental for ensuring that schools are informed about technologies, inquiry-based skills, and research tools (Hoffman-Sartor, Hartley, Seslija, Martinovic, & Adeyemi, 2015; Lewis-Longmuir et al., 2014). These aspects are very important according to the recent policy documents, but are hard to achieve as the budget cuts diminished the number of boards in Ontario with teacher-librarians and school library commons programs (Ontario Library Association, 2006).

We have engaged in many conversations with teachers in schools across Ontario[1], and there are common threads that run through all of them. Teachers often talk about the pressures that they face in their classrooms and the lack of professional knowledge, support and resources. Enter any school and ask teachers what their current struggles are and you inevitably hear, "we weren't trained for this," "it isn't what I went to school for," "we don't have time to learn the new thing," "I can't possibly do that in addition to my current work load." These statements are true and valid.

---

[1] Ontario is the largest province in Canada that in many ways has a lot of influences on the rest of the country.

Perhaps there is a bigger issue that underpins the pressure that educators feel. John White, a professor at University College London, calls us to unpack the school education and ask "[t]he most important question … 'What is it for?'" (2007, p. 26). In response to this call, Aldrich (2010) digs deep into the history of education, identifying its three aims which co-exist: "education for salvation, education for the state and education for progress" (p. 4). Education for salvation is largely religious, faith, and church education, and its goal is for pupils to accept a certain belief system and follow its principles of morality. Education for the state is public education, one that promotes "social cohesion and group pride" (p. 9), while education for progress aims to ensure pupils' employability and economic success of the society. Along these lines, Popkewitz (2011) describes educational philosophy that guided the development of the school curricula:

> When examined, the particular rules and standards for teaching the school subjects of mathematics, literacy, music and social studies education had more to do with the converting ordinances of pedagogy rather than with pedagogies related to learning disciplinary practices. The selection and organisation of school subjects was, at one level, to bestow moral grace on the nation and the promise of progress. Although possibly seeming far-fetched today, school textbooks in the nineteenth century taught geometry and chemistry as bringing progress to the lands of the West through their use in mining and smelting. (p. 15)

In words of Popkewitz, schooling was, and still largely is, driven by the ideas of "who the child is, who it should be, and who does not 'fit' the envisioned future," and "reforms are to create more effective and efficient 'delivery' of learning" (p. 15). Our current model of school traces back hundreds of years, but was never designed for learning as we understand it today. If you examine the history of school, it began as a place where children were housed and taught very basic grammar and arithmetic (Pedersen, 2012). The purpose of school was to socialize children to become the workers needed in the newly emerging industrial economy and so the system was composed to suit this purpose. Schools were never intended to promote skills of inquiry, critical thinking, innovation and creativity. They were institutions that valued transmission and retention of information, and development of workplace skills. The teacher was at the front of the room, the keeper of the knowledge and would impart information to the student who would, without question or query, feed it back to the teacher. School was set up in grades based on chronological age and children had to pass a set of evaluative markers in order to move on to the next grade. Children were expected to be compliant, obedient, and complacent. Teachers were expected to be the holders and knowers of all information. In fact, many of the norms that compose what we call school today (e.g., school day, school year), have deep historical roots, never intended to support learning.

Work in the field of psychology (e.g., in the US—John Dewey, 1859–1952; in Switzerland—Jean Piaget, 1896–1980; and in the Soviet Union—Lev Vygotsky, 1896–1934) as well as the political and social changes have helped to shift this perspective, but the school system has largely stayed intact. Constructivists have long argued that learning requires active participation on the part of the learner (see e.g., Fosnot & Perry, 2005) and although the purpose of education has changed, the model has not. When a society decides that every child has the right to a high quality education (e.g., such that "[empowers] learners to better discern and comprehend what is in the world and to respond intelligently and sensitively to it," Stewart, 1993, p. 9), that "learner differences [are] resources to be used, not obstacles to be confronted" (Wilson & Peterson, 2006), that every child can learn, and that it is the responsibility of the educational body to ensure this—it has an immense impact. But the pressure lands squarely on the shoulders of educators, while the structures and systems that make up school are left unchanged.

For example, many school systems still have summers off. Historically, this was because agrarian children were required to work on the family farm (Pedersen, 2012). Research tells us that summer lag is an impeding issue for many—most students (Alexander, Pitcock, & Boulay, 2016). Yet, we (in the Northern Hemisphere) still count down the days until June especially because the physical structure of the school building is not built for learning in the summer months (when it gets too hot to remain in it throughout the day).

The roles of educators is another organizational oversight. While the role of the Principal began as the lead teacher, over the years, drastically new responsibilities were added to the role. In addition to being instructional leaders, Principals are "setting a school vision, planning instruction, managing the building, human resources, and evaluating and developing teachers' skills" (Bohn, 2013, para. 5; Norton, 2015), yet the idea that there is one principal teacher in any given school, remains the same.

Perhaps we can use the metaphor of a 150-year-old house. If you imagine this house being built in 1870, its construction was based on the needs of the nineteenth century family. It would not have had wiring for electricity or pipes for plumbing. For heaven's sake, it was never built for WI-FI, but here we are, living in it. When we look around at all of the improvements we need to make, increasing the bandwidth seems significantly less urgent than indoor plumbing, but because of surmounting pressures we use our limited resources and retrofit a short-term improvement that increases our Internet speed.

We often approach educational programming from the same 'retrofit' perspective. We scrounge for funding to address a pressing need or a current issue. We seek short-term fixes and patch together repairs which almost never include plans that address the fundamental structure and long-term goals of living in our historic home.

We do not believe that our house needs to be torn down. In fact, it is a Heritage Site, meaning that there are elements in the frame and facade that are worth saving, but perhaps we need to consider how things might change if we decided to remodel. Unlike a retrofit, a remodel begins with a vision and projects are addressed in a systematic way. When you remodel, you make different decisions with the same resources. If we did this, we would end up with a house fit for the twenty-first century. If, on the contrary, we keep retrofitting, we end up with light switches that turn on the toaster!

If schools were truly learning organizations, then any new learning would set off a series of actions intended to achieve the goal. A shift in policy or position would put into motion new learning. We would have systems in place to tackle any new goals. But we do not.

The recent focus in Ontario on improving student achievement in mathematics has amplified our systemic deficiencies (e.g., “deficit-driven meritocracy,” Zhao, 2016, p. 718), that are common in education. Namely, the system is made with the intent “to cultivate and select desirable attributes [in children] and suppress and eliminate undesirable ones,” p. 726), and thus the name “deficit-based” approach. We do not have structures in place to effectively and efficiently change mathematics instruction and so impact student achievement in every classroom. The barriers are real and there are many, but we remain optimistic because our work has documented the great innovations of educators that are influencing systemic changes. They are the lead learners and leaders of our schools.

These introductory musings described schools as historically not created for today’s learning and educator’s role as becoming increasingly complex and difficult. The newest reforms require schools to educate children in novel ways, while keeping the inadequate system structure. We used the metaphors of remodeling and retrofitting, making a case that the first is more suitable, while the second is more frequent approach in educational change. In the next section, we present in more detail some recent educational reforms in Ontario and elaborate on aspects important for success of these reforms. We also describe a longitudinal collaboration between our two institutions, a school board and a university, which supports the claim that educators’ collaborative inquiry (CI) enhances teacher agency and teamwork, fortifying both their professional learning and the school reform. After providing findings from this ongoing project, we reflect on the ways in which schools could more effectively adapt to the new era.

2 The Newest Reforms in Ontario

In his recent 2014 AERA Distinguished Lecture, Anthony Bryk (Former President of the Carnegie Foundation for the Advancement of Teaching; 2014), criticized many education policy changes which appeared abruptly, and while they occupied both media and professional conversations in schools, these reforms resulted in actions or calls for action without providing clear evidence that they will bring a real positive change and in which way. His examples include reformers attempting to improve in-service teacher professional development by introducing instructional coaches in schools, without having the criteria for selecting coaches or expectations of their work, as well as expectations from their organizations in support of their work.

- In Ontario, the recent mandate to improve student achievement in mathematics (Ministry of Education, 2016) has induced anxiety in many school boards, as they were expected to drastically improve the quality of mathematics teaching. Although these improvements may be necessary, there was little guidance on how to lead or support these reforms at the system or school level. In 2016, the Ontario Ministry of Education asked that all elementary schools have up to three ‘math lead teachers’ (i.e., current school teachers “whose responsibility is to deepen their math knowledge through professional learning, to apply this learning in the classroom and to share strategies for learning with other teachers in their school," p. 5). The educator communities needed to understand the meaning of the position, as well as the requirements and skills of the 'math leads.'

Bryk (2014) mentions that reforms, although rooted in some research evidence and initially welcomed by practitioners, have unclear implementation strategy, which may result in frustration, disappointment, and disengagement of practitioners from the reform efforts.

- Recently, Ontario also went through a reform of its Bachelor of Education (BEd)[2] programs. The Ministry of Education required that teacher education extends from a one- to a two-year program, but teacher educators and educational researchers feared that the students will potentially just get "twice as much of the old thing"!

We maintain that by simultaneously enhancing pre-service learning and in-service professional learning (both formal and informal), many of these ambitious reform plans could be achieved. For example, with the mandatory two-year BEd program in Ontario, faculties of education have an opportunity to explore new directions for teacher preparation and to adopt the idea of the teacher-as-researcher (Cochran-Smith & Power, 2010) and teacher-as-leader (Fullan, 2005; Harris, 2005). In such a way education system would embrace new methods of the twenty-first century learning, including staffing schools with teacher-researchers, organizing schools as centres of inquiry, and promoting an inquiry-based leadership (Carpenter, 2014).

3 Which Educator Actions Are Key for the Reform?

In this section, we focus on the three areas closely related to our work: (a) collaborative inquiry, as a vehicle for professional learning; (b) building a culture of inquiry through the school-based research; and, (c) teacher agency. According to Baker-Doyle and Gustavson (2016), teacher agency and collaboration are key factors in school reform and professional development, and both are utilized in a CI.

3.1 Professional Learning Through Collaborative Inquiry

Teacher professional learning is essential for success of educational reforms (Butler, Schnellert, & MacNeil, 2015), school reforms, and innovative practice (Kyndt, Gijbels, Grosemans, & Donche, 2016). Yet, there is little consensus about what ele-

---

[2] Teacher Certification.

ments constitute effective models of professional learning (Guskey, 2003). Kennedy (2016) defines four types of professional development programs, each with an increased reliance on teacher autonomy. Least autonomy teachers have when participating in the *prescribed* programs, and most autonomy when the programs are introduced as a *body of knowledge* (similar to how learning happens in a graduate program). In between the two are *strategies*—programs which may be prescriptive but also provide a rationale (i.e., why they work), and *insights*—programs in which participants are expected to evaluate and interpret what is presented to them. Kennedy found that professional development "program design features [e.g., duration, topic, types of learning activities] may be unreliable predictors of [its] success" (p. 971). However, some strategies worked better, such as learning content knowledge incorporated in a broader context (e.g., of enhancing classroom discourse). Also, mandatory models of professional development may be less effective than the self-directed professional learning, as it may not have a buy-in from the teachers. As stated in the Ontario Ministry of Education (2010, 2014) documents, the school-based, job-embedded professional learning opportunities, based on CI, are paramount to for developing high-quality teachers and ultimately, achieving goals of the recent reforms.

The models, like CI, support teachers' skill development, which lead to systemic changes. This was a finding of a longitudinal case study conducted by Butler et al. (2015) in an urban public school board in Western Canada. This study supports the notion that CI contributes to professional learning of in-service teachers, shifting the norms surrounding their current classroom practices. Butler et al. recognized the gap in research in relation to determining which elements of CI must occur for teachers to become invested in a system change (e.g., district-wide; across a province or state). To address this gap, Butler et al. qualitatively investigated how the educators' perceptions were related to and have changed through the CI focused on improving adolescent literacy. The authors concluded that:

1. The initiatives that encourage and support educators' engagement in inquiry, "can nurture self-efficacy across stakeholders," and in turn "be influential in sustaining a systems-level initiative" (p. 21).
2. "The vast majority of teachers … described ways in which they were taking action, on their own and together, to have an impact in their schools (i.e., agency), and perceived themselves as capable of achieving valued goals for students' and/or colleagues' development (i.e., efficacy)" (p. 22).

Educators in Butler et al. study ($N = 43$, including the Central Board Staff, and administrators and teachers from four secondary and one elementary school), generally positively attributed their growth to the CI experience, thus suggesting a correlation between positive self-perception and high comfortability as agents of a CI model. Almost half of them (mostly those in instructional and administrative leadership roles) saw importance in supporting teachers' sense of agency and distributing leadership for the purpose of systemic change.

3.2 Building a Culture of Inquiry

When a school is focused on building a culture of learning, its educators are required to use data to inform their decisions. Although it is crucial for educators to know how to utilize school data (e.g., assessment, school climate, behavioral, and regular classroom data; Datnow & Hubbard, 2016; Gummer & Mandinach, 2015), this training is not typically part of formal teacher education. It is however a skill that could be obtained through CI.

The importance of educators' capacity building for data use have risen in the last two decades with public outcries for accountability of education, which resulted in the regular state-wide testing of students in mathematics and literacy (e.g., since 2002, with The No Child Left Behind Act in the USA; since 1996, The Education Quality and Accountability Office testing in Ontario). While these tests emphasize importance of regular and controlled collection of education data, in some teachers these may create a narrow view that data arise only from the periodical tests, which may consequently result in an aversion towards data.

To clarify these issues, Datnow and Hubbard (2016) conducted a literature review of about 60 resources, published in English since 2001, which addressed K-12 teachers' capacity to use data or their beliefs about data use. Study findings suggest that when teachers are grouped with other teachers (either from the same grade level or subject area), administrators, instructional coaches, university researchers, or facilitators, then it is much more likely that an improvement will be seen in teachers' capacity building for data use. However, as long as teachers consider data use connected only to outward accountability (to the Principal, the school board, or the government), they will see themselves as subjects, rather than agents of change. The shift in educators' thinking about data needs to happen for evidence-based instructional planning to become a key component of teaching.

While the recent push towards the evidence-based education resulted in the more widely accepted idea that developing research skills by the teachers should be built into the school's professional development planning, Biesta (2007) cautions that "'Evidence'—if such a thing exists—does not provide us with rules for action but only with hypotheses for intelligent problem solving" (p. 17). Consequently, the research-engaged school should follow the external research results while simultaneously building a professional learning capacity of its staff that includes the home-grown inquires.

According to Handscomb and MacBeath (2003), a research-engaged school has "a research rich pedagogy" as well as "a research orientation." In addition, it is an educational institution that "promotes research communities" and "puts research at the heart of school policy and practice" (p. 4).

When the school staff engages in inquiry, then the school experiences "a paradigm shift from a data provider culture to a data user culture" (Johnson & Bush, 2005, p. 276). Instead of only providing data to the board, government and researchers, the school is enabled to

> [D]efine indicators of progress including the distribution of learning opportunities, to test assumptions about students and their experiences, and to encourage more provocative

> inquiry about institutional practices that contribute to performance. The new paradigm includes constant internal monitoring of progress toward goals. (p. 276)

Building a school culture that supports individual, small group, or whole-school inquiry leads educators to engage in a research-based change of their practice or other aspects of their professional environment, and evaluation and comparison of existing programs or curriculum approaches. For this to happen, educators need to have (among else): "[a] sense of permission to work differently," granted by the school's leadership team; "[a] sense of support from the organisation and the wider system," such as providing conditions for staff to engage in research, focusing on research-related PD, and involving in collaborative networks run by universities; and "[a] sense that success will be marked by recognition in desirable ways" (Wilkins, 2011, p. 9; e.g., by creating opportunities for educators to present their work at conferences or similar knowledge dissemination venues).

3.3 Teacher Agency

When teachers have a sense of control over their professional lives, they exercise their agency (Butler et al., 2015). Hargreaves and Fullan (2013) introduce a notion of professional capital of teachers (i.e., human, social and decisional capital), and praise Ontario where CI is not utilized as a "quick fix" for increasing achievement scores on standardized assessment. Rather, teachers and school leaders tend to collectively take responsibility for their student success and focus on enhancing their collaborative learning.

In order for teachers to focus on students, something that across the studies they emphasize as the most professionally important, they first must become learners themselves. Grossman, Wineburg, and Woolworth (2001) suggested that, through learning communities, teachers put themselves into the students' shoes as they are vulnerable and learn new things. This promotes the notion that all members of a learning community are learners. Teachers must share their expertise in order to learn from one another, noting that the knowledge of the entire group is greater than that of any individual teacher. Every person in the community has something to offer.

4 Introducing the Collaborative University-School Board Project

The ideas of professional learning through CI, engaging schools in research, and building teacher agency are at the core of our work. Our partnership was initially informed by results of a survey of about 600 educators from 16 school boards in the South-West Ontario, in which, 80% of them reported that they would participate in research, and identified not understanding research methodology and a lack of training as barriers to conducting research (Martinovic et al., 2012). While we believed that teachers and research go hand-in-hand, that study suggested that teachers need to get used to the idea that they may be expected to do research.

In the same year, our two institutions established a research partnership. One aspect of this ongoing project was to engage school teachers in collaborative research practices with faculty members (Fig. 1). It organically surfaced into a longitudinal concurrent transformative mixed-methods case study (Creswell, Plano Clark, Gutmann, & Hanson, 2003), through which we investigate what changes when educators engage in a school board-level, inquiry-based initiative.

For this project we would annually fund 11–15 CI teams and associate university researchers to them. At a beginning of the school year, the school board would issue a call to all schools, inviting educators to form the CI teams, and propose their topics and inquiry questions. Teachers received four half days of release time for team work, and also participated in a half-day launch session in October and a full day Learning Fair in May (Fig. 2). The research team collected data in an iterative way,

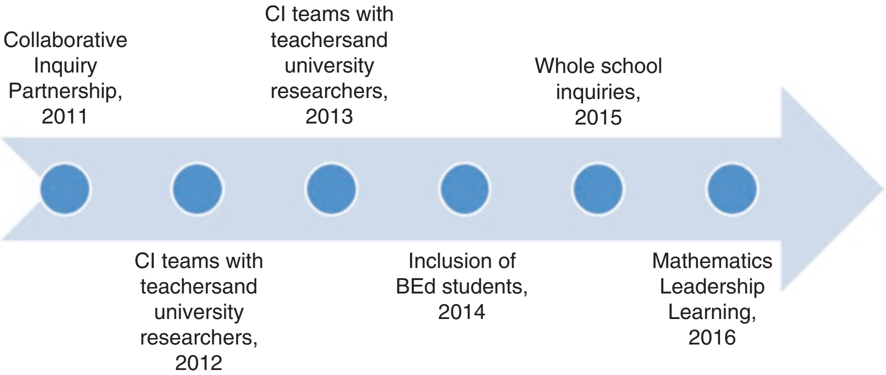


Fig. 1 Evolution of the collaborative project

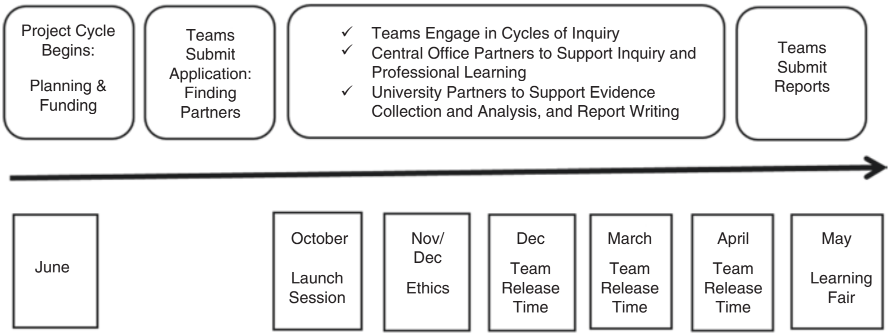


Fig. 2 A typical year of the CI planning

thus cycling back and forth between quantitative and qualitative data collection (Creswell et al., 2003). Because of the complexity of the project and obligations towards different funding sources, we collected and integrated both quantitative and qualitative data, as well as integrated all findings in our annual reports.

For example, during the 2014–15 school year, we engaged in this project 65 educators from 21 schools, 8 program staff, 2 faculty members, 4 graduate students, and 3 teacher candidates (this was the first time that we piloted adding teacher candidates to the CI teams). We had three CI projects about mathematics, four projects about Michael Fullan's "6 C's" (character education, citizenship, communication, critical thinking and problem solving, collaboration, and creativity and imagination; Fullan, 2016) and student inquiry; two projects about collaboration and the learning commons; two projects about mindfulness; and one each about habits of mind, flipped classroom, inquiry in music, literacy, and pathways for students with learning difficulties. The CI teams' research ideas/questions raised from their teaching practice and their own research interests which they called "the itch," "the need to change," or the "curiosity of the team." Intrinsic motivation helped them to get the clear goal to follow and to ignite the desire to explore and to learn, resulting in awareness of "how much has changed in a few short months." During the Learning Fair the teams presented their work with much passion, and sense of pride and achievement. They stated that working with the board and university researchers "has been instrumental in moving us forward," because they offered the team "the outside perspective we needed." The project team had a sense that we reached a place where system innovation happens!

This project was the foundation for our current work in supporting a distributive mathematics leadership model. Our years of supporting CI projects helped to create the conditions for which teachers were primed to emerge as leaders and researchers, ready to tackle the challenge of mathematics reform.

The provincial shift in focus to improve student achievement in mathematics had tremendous impact on the scope of this project. Although our research supported the idea that CI was an effective professional learning model, the current reform was accompanied by a more aggressive and highly politicized tone to shift teaching practices (i.e., the media used the language of "national emergency," "Ontario's math problem," and "children at the mercy of the curriculum"). Educators across Ontario were encouraged to develop their mathematical pedagogical-content knowledge (Evens, Elen, & Depaepe, 2015; Shulman, 1986). The open nature of CI did not fit the urgency of the mandate or the current reality of what teachers needed to support their growth as mathematics educators. However, we knew that deserting the agency and leadership that had been developed over the years would be a huge step backward.

In the first year of the Ontario Renewed Math Strategy (Ministry of Education, 2016) the school board concentrated efforts on building the mathematics content, pedagogy and leadership capacity of educators. They were identified as formal leaders (central office and administration) and school-based mathematics learning teams. Our work since then, sparked many questions about mathematics leadership. In the late 2016, our two organizations committed to focus our efforts on better understanding mathematics leadership and we were granted with leading the Mathematics Leadership Community of Practice, as part of the Ontario Mathematics Knowledge Network (MKN, see http://mkn-rcm.ca/). The principles of our CI project (i.e., developing capacity in a way which honours personal needs and professional strengths of educators) are woven through the current work of building capacity for leading mathematics learning. This time we are focusing on the professional learning of math leads in the Board and on five Mathematics Leadership Learning Projects (MLLP)—the whole-school inquiries—aimed at understanding what model might support school improvement and mathematics leadership.

4.1 The Mathematics Leadership Learning Projects (MLLP)

The partnering school board has identified building the content-pedagogy and leadership capacity of school and system mathematics leaders as one of the central goals of the 2016–2017 school year. School mathematics leaders have engaged in multiple forms of learning designed to support their capacity as leaders. Each of the five MLLP schools have been supported with release time, resources, central office and the MKN support to build a Mathematics Leadership Learning Project. Each of the five schools developed a school-based leadership project. The purpose of these projects was to build the mathematical expertise of all educators within the schools and inform similar projects across the Board and the Province. The data collected from these schools will help build a better understanding of mathematics leadership in the Ontario context.

Multiple forms of data including: interviews, surveys, artifacts, notes and reflections are collected throughout this study. The data are gathered and analyzed by the school teams in collaboration with the Mathematics Leadership Community of Practice in order to answer our central question: *Which learning experiences had the most impact on members of the MLLP teams?* Schools are collecting data that help to inform the effectiveness and impact of their plans.

> In the MLLP, there was a sense that we are embarking onto an uncharted territory:
>
> From the perspective of our board, the expectation (from the Ministry) for math leads is unclear. Our work has been to develop a model of distributive leadership in which math leads take on instructional leadership within schools. We understand that this process is complex. This year we wanted to wade in... Slowly.
>
> - We needed to better understand teacher expertise in mathematics and the role of the lead.
> - We do have a plan moving forward but it is early in the formalization process.
> - We also know that mathematics pedagogy needs to be further investigated, extended and refined and this is also the work of mathematics leaders. (Consultant, January 2017)

Through this work, we observed the changing roles of facilitators and leaders at all levels. We noted that when the school administrators were comfortable within their role as instructional leaders and had previous experiences in CI, the school board facilitator's role was more consultative in nature. This is consistent with the findings from Australia, where "the development of a school wide approach to pedagogy and its implementation needs to be firmly embedded in the leadership of learning" (Conway & Andrews, 2016, p. 115). It recognizes mutually supportive and parallel leadership opportunities in schools where teacher leaders' creativity and expertise contribute to professional revitalization of schools, while administrative leaders contribute their vision about the school identity and create opportunities for action.

Collective teacher efficacy is a property of school (Goddard, Hoy, & Hoy, 2000); it "is positively associated with the differences in student achievement that occur between schools" (p. 501). It is seen in teachers' belief in their collective ability to educate students, and "acceptance of challenging goals, strong organizational effort, and a persistence that leads to better performance" (p. 486). This important learning connects all five very different whole-school projects, which evolved into the mathematics leadership learning schools. Other commonality is that all five projects are moving towards inquiry-based (mathematics) leadership (Carpenter, 2014), involving school administrators, the core team of teachers, and the school community.

The connections between the CI, whole-school inquiry, and the mathematics leadership learning stages of our project are described in the reflections from the same consultant:

> The project is very similar to the way in which we engage in collaborative inquiry. These schools look like the work of our whole school inquiries. But, there is a notable difference here. I think it is the concept of "leadership" and this is a big idea! For some… perhaps for many… teacher-leader is an oxymoron. Why?
>
> It was striking to see how uncomfortable the teachers were with the idea of leadership…
>
> Our conversation began with a discussion prompt, "what is mathematics education leadership?" It was difficult to describe, and the collective agreed that they were not leaders. They wanted to be collaborators, who shared ideas with staff, learned together, figured things out together, pressed for change in subtle, collegial, collaborative ways. For these teachers this was not leadership. One teacher remarked, "I don't look at it as leadership, I look at it as collaboration. It looks like us working together to learn more. It isn't about us telling people 'do this,' it is about us working together."
>
> If one's definition of leadership is predicated on the idea of authority, then it is understandable that these teachers do not see themselves as leaders. The issue is not their plans, ideas or actions, it is that they have long been immersed in a world where boss and leader where intermingled terms. These terms are, in fact, not the same thing, but this may be something that these educators need to discover. They are leaders. I see it and I believe they will, in time. (Consultant, June 2017)

By December 2017, the facilitators noticed that the conversations in schools have changed; the term "math leader" stopped being a stumbling block. The project team hypothesized that the Math Leadership Learning approach was successful, as it was asset-based; the schools had autonomy, they could exercise creativity and collaboration. This model was learning-based, not outcome-based. The driving notion became, "You cannot know your learners, if you do not know mathematics first!"

5 Conclusions

In this chapter, we presented the challenges that Ontario educators face in view of the recent education reforms. These changes call for the accelerated professional learning, which will result in staffing schools with teachers-researchers, organizing schools as centres of inquiry, and promoting an inquiry-based leadership (Martinovic, 2017). The evolution and outcomes of the joint school board-university project since 2011, have similarly impacted the practice of hundreds of teachers and influenced the structures of the entire system. The project has supported the rise of teacher leaders and the Mathematics Leadership Learning Project. The tenets of the project and strength of the partnership has allowed for unique opportunities for teachers to engage in inquiry and build their professional capacity, thus affecting their agency and efficacy (Butler et al., 2015). These teacher-led CIs have provided educators with significant exposure to research methods, tools, and outcomes, which have influenced the growth of school-based leadership—now a common structure across the school board.

Broadly, it became clear that with recent shift towards enhancing mathematics education in Ontario, school board and school-based educators in all roles require support in developing mathematics content and pedagogy; a goal which we approached by providing structures for collaborative learning (e.g., Ferguson & Hirsch, 2014; Hargreaves, 2003). Specifically, the level of content, pedagogy, and leadership knowledge of administrators, math learning teams and central office staff differs. This understanding is based on our current data and continues to inform our work in building the capacity of mathematics leaders.

What can be done to support teachers in the era of change? Along with Priestley, Biesta, Philippou, and Robinson (2016), we believe that "the concept of teacher agency in general, and the ecological approach in particular, potentially offers a means for arresting and even reversing twenty five years of misguided regulation of the work of teachers" (p. 21). Schools and school boards should prioritize professional learning models that encourage collaboration, agency, distributive leadership and research.

Bryk (2014) emphasized that for education to go through a systematic improvement, we need to use "disciplined, analytic, and systematic methods to develop and test changes that achieve reliable improvements"; to bring together "expertise of practitioners, researchers, designers, technologists, and many others"; and to accept that in education, "practice-based evidence" has value as a "local learning activity" (such that it is contextualized and inclusive of the practitioner's knowledge). Education system needs to act as a learning system (similar to calls that schools become "learning organizations"; Bridich, 2015). For this to happen, the following challenges need to be considered: (a) adopting models that support teacher leadership; (b) adopting a common understanding of the reform measures and practices; (c) creating conditions for reciprocal relationships between stakeholders (e.g., dealing with unequal access to knowledge, and distinctions between producers and recipients of knowledge); (d) enhancing PD of educators and mobilizing knowledge to build capacity and spread; (e) working together as a professional learning community and engaging in timely, public conversations on educational issues to create value added information for both researchers and practitioners; and (f) balancing reform changes with research supports and challenges of implementation.

We believe that through our collaboration we were able to address most of the ideas suggested by Bryk (2014) and Bridich (2015), and the OECD recommendations stating that: “the teaching profession must be trained and equipped so that it will have the capacity to cope with the many changes and challenges which lie ahead” (Coolahan, 2002). We recognize that teachers are required to re-visit their philosophy and priorities, and dramatically alter their role and practices in the era of continual education reforms. However, we argue that, “coping” is insufficient and we should aim for systems in which teachers have ownership of these reforms. The CI may be a reachable pathway to help teachers build their professional knowledge, build a school-wide culture, and, by enhancing teacher agency, support the prosperity of them as learners.

References

Aldrich, R. (2010). Education for survival: An historical perspective. *History of Education, 39*(1), 1–14.

Alexander, K., Pitcock, S., & Boulay, M. (Eds.). (2016). *The summer slide: What we know and can do about summer learning loss*. New York, NY: Teachers College Press.

Baker-Doyle, K. J., & Gustavson, L. (2016). Permission-seeking as an agentive tool for transgressive teaching: An ethnographic study of teachers organizing for curricular change. *Journal of Educational Change, 17*, 51–84.

Biesta, G. (2007). Why “what works” won’t work: Evidence-based practice and the democratic deficit in educational research. *Education Theory, 57*(1), 1–22.

Bohn, J. (2013). First year hurdles. *The Principalship, 70*(7). Retrieved from http://www.ascd.org/publications/educational_leadership/apr13/vol70/num07/First-Year_Hurdles.aspx

Bridich, S. (2015). The invisible schism: Teachers’ and administrators’ differing perceptions of education reforms. *Education Policy Analysis Archives, 24*, 87. Retrieved from https://doi.org/10.14507/epaa.24.2192

Bryk, A. S. (2014). AERA distinguished lecture: Accelerating how we learn to improve. *Educational Researcher, 44*(9), 467–477.

Butler, D. L., Schnellert, L., & MacNeil, K. (2015). Collaborative inquiry and distributed agency in educational change: A case study of a multi-level community of inquiry. *Journal of Educational Change, 16*(1), 1–26.

Cameron, D., Kokis, J., & Ryerson, R. (2014). *Understanding collaborative inquiry for professional learning*. Presented at Ontario provincial meeting of Student Achievement Officers, April 9, 2014. Toronto, ON.

Carpenter, B. (2014). Inquiry based leadership – A 21st century challenge. 2014 Division of Educational and Child Psychology Annual Development Event. Oxford, England. Retrieved from http://www.bps.org.uk/bpslegacy/conf_abstracts?&ResultsType=Abstracts&ResultSet_ID=10730&FormDisplayMode=view&frmShowSelected=true&localAction=details

Cochran-Smith, M., & Power, C. (2010). New directions for teacher preparation. *Educational Leadership, 67*(8), 6–13.

Cohen, D. K., Spillane, J. P., & Peurach, D. J. (2018). The dilemmas of educational reform. *Educational Researcher, 47*(3), 204–212.

Conway, J. M., & Andrews, D. (2016). A school wide approach to leading pedagogical enhancement: An Australian perspective. *Journal of Educational Change, 17*(1), 115–139.

Coolahan, J. (2002). *Teacher education and the teaching career in an era of lifelong learning*. OECD Education Working Papers. Paris, France, pp. 1–39.

Creswell, J. W., Plano Clark, V. L., Gutmann, M. L., & Hanson, W. E. (2003). Advanced mixed methods research designs. In A. Tashakkori & C. Teddlie (Eds.), *Handbook of mixed methods in social and behavioral research* (pp. 209–240). Thousand Oaks, CA: Sage.

Crowther, F., Ferguson, M., & Hann, L. (2009). *Developing teacher leaders: How teacher leadership enhances school success* (2nd ed.). London, UK: Sage.

Datnow, A., & Hubbard, L. (2016). Teacher capacity for and beliefs about data-driven decision making: A literature review of international research. *Journal of Educational Change, 17*, 7–28.

Donaldson, G. (2010). *Teaching Scotland's future: Report of a review of teacher education in Scotland*. Edinburgh, UK: Scottish Government.

Evens, M., Elen, J., & Depaepe, F. (2015). Developing pedagogical content knowledge: Lessons learned from intervention studies. *Education Research International.* Retrieved from https://doi.org/10.1155/2015/790417.

Ferguson, R. F., & Hirsch, E. (2014). *How working conditions predict teaching quality and student outcomes*. In T. J. Kane, K. A. Kerr, & R. C. Pianta (Eds.), *Designing teacher evaluation systems: New guidance from the measures of effective teaching project* (pp. 332–380). San Francisco, CA: Jossey-Bass.

Fosnot, C. T., & Perry, R. S. (2005). Constructivism: A psychological theory of learning. In C. Fosnot (Ed.), *Constructivism: Theory, perspectives, and practice* (2nd ed., pp. 8–38). New York, NY: Teachers College.

Fullan, M. (2005). *Leadership and sustainability: System thinkers in action*. Thousand Oaks, CA: Corwin Press.

Fullan, M. (2016). *Great to excellent: Launching the next stage of Ontario's Education Agenda*. Retrieved from http://michaelfullan.ca/wp-content/uploads/2016/06/13599974110.pdf

Goddard, R. D., Hoy, W. K., & Hoy, A. W. (2000). Collective teacher efficacy: Its meaning, measure, and impact on student achievement. *American Educational Research Journal, 37*(2), 479–507.

Grossman, P., Wineburg, S., & Woolworth, S. (2001). Toward a theory of teacher community. *Teachers College Record, 103*(6), 942–1012.

Gummer, E., & Mandinach, E. (2015). Building a conceptual framework for data literacy. *Teachers College Record, 117*(4), 1–22.

Guskey, T. R. (2003). Analyzing the lists of characteristics of effective professional development to promote visionary leadership. *NASSP Bulletin, 87*(637), 4–20.

Handscomb, G., & MacBeath, J. (2003). *The Research Engaged School. Forum for Learning and Research Enquiry (FLARE)*. Essex, UK: Essex County Council.

Hargreaves, A. (2003). *Teaching in the knowledge society. Education in the age of insecurity*. New York, NY: Teachers College Press.

Hargreaves, A., & Fullan, M. (2013). The power of professional capital. *Journal of Staff Development, 34*(3), 36–39.

Harris, A. (2005). *Crossing boundaries and breaking barriers: Distributing leadership in schools*. iNET pamphlet. London, UK: Specialist Schools Trust. Retrieved from http://www.almaharris.co.uk/files/distributed_leadership_pamphlet.pdf

Hoffman-Sartor, T., Hartley, I., Seslija, S., Martinovic, D., & Adeyemi, A. (2015). *Eliciting collaboration between the teacher librarian and classroom teacher to create an inviting, accessible learning commons space and improve student information literacy skills*. Collaborative Inquiry Reports 2014-2015, Vol. 7, pp. 24–31. Reprinted in Canadian School Libraries Research Archive, http://researcharchive.canadianschoollibraries.ca/wp-content/uploads/2017/10/TMC4_2016_Sartor.pdf

Johnson, R., & Bush, L. V. (2005). *Leading the school through culturally responsive inquiry*. In F. W. English (Ed.), *In the Sage handbook of educational leadership: Advances in theory, research, and practice* (pp. 269–296). Thousand Oaks, CA: Sage.

Kelly, H. (2004). This addictive thing called teaching: An interview with Sonia Nieto about what keeps teachers going? *Educational Studies Journal, 35*(2), 158–174.

Kennedy, M. M. (2016). How does professional development improve teaching? *Review of Educational Research, 86*(4), 945–980.

Kyndt, E., Gijbels, D., Grosemans, I., & Donche, V. (2016). Teachers' everyday professional development: Mapping informal learning activities, antecedents and learning outcomes. *Review of Educational Research, 86*(4), 1111–1150.

Lewis-Longmuir, A., Duym, N., Martin, M., Lawler, J., Seslija, S., Tompkins, K., et al. (2014). *What impact does the collaboration between the classroom teacher and the teacher-librarian have on the attitudes of the classroom teacher towards inquiry-based learning?* Collaborative Inquiry Reports: Teachers creating knowledge and improving learning for students, 2013-2014. Vol. 6, pp. 115–126. Reprinted in Canadian School Libraries Research Archive http://researcharchive.canadianschoollibraries.ca/wp-content/uploads/2017/10/TMC3_2014_Seslija_Pt1.pdf

Martinovic, D. (2017). *Increasing cohesion between Educators' communities: Utilizing research partnerships and knowledge brokering*. Tips from the Experts: 12 July 2017. Retrieved from https://www.knaer-recrae.ca/tips-from-the-experts/216-increasing-cohesion-between-educators-communities-through-research-partnerships-knowledge-brokering

Martinovic, D., Wiebe, N., Ratkovic, S., Willard-Holt, C., Spencer, T., & Cantalini-Williams, M. (2012). 'Doing research was inspiring': Building a research community with teachers. *Educational Action Research, 20*(3), 385–406.

Martinovic, D., Winney, K., & Dabaja, Z. (2017). *Developing Professional Capital through Collaborative Inquiry: Working through tensions*. International Congress for School Effectiveness and Improvement (ICSEI) 2017, January 7–10, Ottawa, ON.

Martinovic, D., Winney, K., & Knight, C. (2015). Imagine the learning! Insights from a Collaborative Inquiry Project in Southwest Ontario. *Learning Forward Ontario, 7*(1), 3–5.

Norton, M. S. (2015). *The assistant principal's guide: New strategies for new responsibilities*. New York, NY: Routledge.

Ontario Library Association. (2006). *School libraries and student achievement in Ontario*. Retrieved from https://www.accessola.org/web/Documents/OLA/Divisions/OSLA/SchoolLibrariesStudentAchievementOntario.pdf

Ontario Ministry of Education. (2010). *Collaborative teacher inquiry*. Retrieved from http://www.edu.gov.on.ca/eng/literacynumeracy/inspire/research/CBS_Collaborative_Teacher_Inquiry.pdf

Ontario Ministry of Education. (2014). *Collaborative inquiry in Ontario*. Retrieved from http://edu.gov.on.ca/eng/literacynumeracy/inspire/research/CBS_CollaborativeInquiry.pdf

Ontario Ministry of Education. (2016). *Ontario's renewed mathematics strategy*. Retrieved from http://www.edu.gov.on.ca/eng/policyfunding/memos/april2016/dm_math_strategy.pdf

Pedersen, J. (2012). The history of school and summer vacation. *Journal of Inquiry & Action in Education, 5*(1), 54–62.

Popkewitz, T. S. (2011). Curriculum history, schooling and the history of the present. *History of Education, 40*(1), 1–19.

Priestley, M., Biesta, G., Philippou, S., & Robinson, S. (2016). *The teacher and the curriculum: Exploring teacher agency*. In D. Wyse, L. Hayward, & J. Pandya (Eds.), *The SAGE handbook of curriculum, pedagogy and assessment* (pp. 187–201). London, UK: Sage.

Serdyukov, P. (2017). Innovation in education: What works, what doesn't, and what to do about it? *Journal of Research in Innovative Teaching & Learning, 10*(1), 4–33.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.

Stewart, D. (1993). Teaching or facilitating: A false dichotomy. *Canadian Journal of Education, 18*(1), 1–13.

White, J. (2007). *What schools are for and why?* London, UK: Philosophy Society of Great Britain.

Wilkins, R. (2011). *School research engagement: Whose agenda? Mapping the landscape for school leaders*. International Congress for school effectiveness and improvement, Limassol. Retrieved from http://www.icsei.net/icsei2011/Full%20Papers/0044.pdf

Wilson, S. M., & Peterson, P. L. (2006). *Theories of learning and teaching: What do they mean for educators?* Washington, DC: National Education Association. Retrieved from http://www.nea.org/tools/theories-of-learning-and-teaching-what-do-they-mean-for-educators.html

Zhao, Y. (2016). From deficiency to strength: Shifting the mindset about education inequality. *Journal of Social Issues, 72*(4), 716–735.

Dragana Martinovic is a Professor of Mathematics Education at University of Windsor, where she leads the Human Development Technologies Research Group. Dragana is a Fellow of the Fields Institute for Research in Mathematical Sciences and a Co-Director of the Fields Centre for Mathematics Education. She is a recipient of the Excellence in Mentoring Award at University of Windsor. In her research, Dr. Martinovic explores ways in which technology can improve teaching and learning outcomes, and the digital literacy skills needed for a successful learner and worker of the twenty-first century. She is dedicated to supporting teacher-led research and providing opportunities for all involved in education to collaboratively work towards increasing student engagement, success, and love for learning mathematics. Dragana is on the Executive for the Mathematics Knowledge Network, hosted by the Fields Centre for Mathematics Education. She co-chairs the Mathematics Leadership Community of Practice (since 2016) and the *Fields Cognitive Science Network for Empirical Study of Mathematics and How it is Learned*, and is a founding and current co-editor of the Springer book series, *Mathematics Education in the Digital Era*.

Heidi Horn-Olivito has been an educator for 17 years, teaching a variety of grades. She was a teaching consultant in the area of research and program evaluation, and is now a school administrator.

Mathematics Teachers Edit Textbooks: Opportunities and Challenges

Ruhama Even

1 Introduction

Research suggests that mathematics textbooks considerably influence classroom instruction. Textbooks are often the main source that mathematics teachers use to plan lessons, to choose the content to be taught and the lesson activities to be conducted (Eisenmann & Even, 2011; Haggarty & Pepin, 2002). Yet, in contrast to their central role in textbook use, mathematics teachers rarely participate in textbook development. Should this situation be changed? What might be gained and what might the challenges be if the community of mathematics teachers is given an opportunity to participate in textbook development?

This chapter addresses these issues by drawing on a set of studies conducted as part of the *Mathematics Teachers Edit Textbooks* (M-TET) research program, in collaboration with Shai Olsher, Ayelet Gottlieb and Michal Ayalon (Even, Ayalon, & Olsher, 2016; Even & Olsher, 2014; Gottlieb, 2016; Olsher & Even, 2018). The first part of the chapter describes the M-TET project, which served as the research setting for the set of studies on which this text draws. Then potential gains and challenges associated with giving mathematics teachers the opportunity to edit the textbooks they use in class are presented and discussed.

2 The M-TET Project

The M-TET project invited mathematics teachers to collaborate in editing the textbooks they used in their classrooms and to produce, as group products, revised versions of those textbooks that would be suitable for a broad and diverse student

---

R. Even (✉)
Department of Science Teaching, Weizmann Institute of Science, Rehovot, Israel
e-mail: ruhama.even@weizmann.ac.il

Y. Ben-David Kolikant et al. (eds.), *STEM Teachers and Teaching in the Digital Era*, https://doi.org/10.1007/978-3-030-29396-3_3

population. For practical reasons, participation in the editing activity was restricted only to teachers who used textbooks from the junior-high school mathematics curriculum program *Integrated Mathematics* (*Matematica Meshulevet*), which was developed at the Weizmann Institute of Science (Friedlander, Even, & Robinson, 2018).

Participation in the M-TET project entailed ongoing online work and monthly face-to-face whole-group meetings. Both the online work and the face-to-face meetings included textbook editing of various types (e.g., adding tasks, changing textbook tasks, and altering the order of textbook tasks), reacting to other participants' suggestions (e.g., supporting, opposing, debating, and elaborating), as well as discussing mathematical and pedagogical issues (e.g., what approach is suitable for students with difficulties, the role of technological tools in mathematics lessons). In addition, the monthly face-to-face meetings consisted of discussions of community working norms (e.g., the issue of amending another teacher's editing suggestion), and receiving instructions on using the technological tool used in the project (e.g., how to edit, react, and view change history).

To enable collaborative textbook editing and the production of a joint revised textbook we used, with some modifications, a modified wikibook platform for constructing the project website. This website served as an online platform for collaborative work on a common database (i.e., a textbook). That is, the textbook was shared and edited collaboratively online. The website also served as a vehicle for discussions in a forum-like fashion (for more information on the technological platform used in the M-TET project, see Even & Olsher, 2014).

Two kinds of support accompanied both the online work and the face-to-face meetings. One was technical support in using the technological platform for textbook editing. The aim of this support was to provide a smooth, efficiently run work environment that enables teachers to perform their desired editing without having to deal with, or be constrained by, technological difficulties. The other kind of support was related to conceptual issues that emerged as part of the editing work. To this end, the participating teachers were offered an opportunity to consult with various professionals throughout their ongoing distance work and during the monthly face-to-face meetings. The professionals made available for consultation included the authors of the *Integrated Mathematics* textbooks, a research mathematician, and researchers in the field of mathematics education.

During the first year of the project (the 2010–2011 school year), the project team purposely avoided intervening in the teachers' work, besides instructing the teachers on how to use the project's website, and answering teachers' queries, as long as they did not request assessment of their work. From the second year onwards, however, the work environment enabled more flexible interactions among the teachers and the consultants. The participating teachers (old-timers and new-comers) continued to have an autonomous work environment where they could freely edit the textbooks and interact with the consultants as they wished. But, the consultants were allowed to initiate comments on the teachers' editing suggestions and could freely address queries raised by them. In addition, a sizable part of the face-to-face meetings was devoted to discussions with the textbook authors and with the mathematician on issues chosen either by the teachers or by the project team.

Next, the chapter focuses on what might be gained and what the challenges might be when such a work environment is offered to teachers. The first two sections center on the potential of the M-TET work environment to reveal teachers' wishes and desires regarding textbooks and possible implications of teachers' textbook editing with respect to the way mathematics is portrayed and offered in the edited textbooks. The following two sections focus on the potential of the M-TET work environment to transform the conventional connections between teachers and professionals that are not part of the teachers' usual milieu: textbook authors and mathematicians.

3 Teachers' Need: Organizing Tools Embedded in the Textbook

Somewhat surprising, although in many countries textbooks serve as a major resource for teachers' work (Eisenmann & Even, 2011; Haggarty & Pepin, 2002), the literature provides little information about teachers' wishes and desires regarding textbooks. Indeed, the literature about curriculum enactment is an important source of information regarding the modifications that teachers make in textbooks when they use them in class (e.g., Drake & Sherin, 2006; Eisenmann & Even, 2011; Tarr, Chavez, Reys, & Reys, 2006), showing discrepancies between the written and the enacted curriculum related to the mathematical content and to the approaches to teaching and learning it. Examples of such modifications include omitting mathematics topics that appear less central, deviating from suggested work settings, lowering the level of cognitive demand in mathematical tasks, and altering mathematical representations.

However, the information regarding the modifications that teachers make in textbooks when they use them in class is restricted by the research setting and its focus on curriculum enactment, on teachers' mobilisation of the textbook, where omissions and insertions are often not based on deliberate and thoughtful considerations (e.g., Leshota & Adler, 2014). Thus, this line of research does not necessarily attend to the changes that teachers wittingly and purposely would choose to make in the textbook they use in class, in contrast to a research setting where teachers develop or edit textbooks.

One of the studies in the M-TET research program (Olsher & Even, 2018) revealed that the unique setting of the M-TET work environment enabled the gaining of novel insights regarding the changes teachers suggest making in textbooks after thoughtful considerations. In this study we analyzed the changes that the teachers who participated in the first year of M-TET proposed when they edited the 7th grade textbook that they used in class. We analyzed only the changes for which the teachers' goals for modification were identifiable. The findings revealed several types of change. Similar to many of the modifications reported in the literature on curriculum enactment, some of these changes were related to the textbook approach to teaching and learning the mathematics content (e.g., integrating technology into textbooks, restructuring textbook content to better suit student learning, and making the textbook more suitable for students with low achievements). However, our analysis also revealed a type of change that is not reported in the literature, which focuses on changes teachers make when using textbooks in class (i.e., comparing the written and the enacted curriculum). This type of change is related neither to the mathematical content nor to the approaches to teaching and learning mathematical content, but rather to making the textbook more user-friendly by creating organizing tools embedded in it.

The study revealed four organizing tools that the teachers chose to construct. Their construction involved: (1) making highlighted content easily accessible, (2) marking the core of the textbook, (3) adding informative titles to units and lessons, and (4) making practice tasks easily accessible. The goals and characteristics of the organizing tools on which the teachers worked are briefly described below. (Detailed information about these organizing tools and the challenges that the teachers faced when constructing them can be found in Olsher & Even, 2018.)

Highlighted contents appeared throughout the textbook the teachers edited in the form of framed short texts. These framed texts had different roles (e.g., lesson summaries, definitions, and comments). The teachers recognized these framed texts as important, and decided to work on making them easily accessible. Their goal was to enable more efficient and diverse use of the highlighted (i.e., framed) texts both for teachers and for students (e.g., quickly finding a specific definition, and reading summaries).

The teachers first tried to categorize the different framed texts according to their roles. However, this categorization was difficult to carry out and the teachers eventually decided to gather all important contents from the framed texts and sort them into different collections, so that each collection was devoted to a single mathematical strand: numeric, algebraic, geometric, and function. This sorting was rather simple to perform except in cases where the contents of framed texts were taken from textbook units that combined several strands. For example, the framed text that presented the distributive property ($a \cdot (b + c) = a \cdot b + a \cdot c$) connected it with two ways of calculating the area of a rectangular gym floor whose one side is a and the other is $b + c$ (see Fig. 1): $a \cdot (b + c)$ and $a \cdot b + a \cdot c$. Thus, the content of this framed text combined algebra and geometry. In such cases, the teachers sorted the framed contents into one strand collection only. For instance, the framed text about the

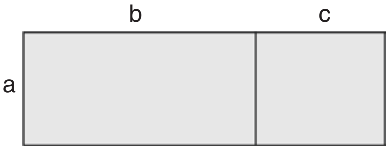


Fig. 1 A rectangular floor whose calculated area demonstrates the distributive property

distributive property was sorted into the algebraic collection only, even though it integrates the algebraic and geometric strands.

In doing so, the teachers altered a key characteristic of the textbook, as well as of the national curriculum (Ministry of Education, 2009, 2013), namely, integration and connections among different mathematical strands. The collections the teachers created presented mathematical contents in a more traditional way that treats each strand as distinct and separate from other strands. Thus, the end result of making highlighted content in the textbook easily accessible was successful by means of providing a simple and convenient way to locate desired highlighted content. However, the collections the teachers created sometimes portrayed this content conceptually different from what was intended, as if different mathematical strands (e.g., algebra and geometry) are disjointed.

Another organizing tool on which the teachers worked involved marking the core of the textbook. The goal of this activity was to make clear for teachers who use the textbook which parts of the textbook are essential, and thus should not be skipped when teaching. Marking the core of the textbook was considered important by the participating teachers. However, it turned out that deciding what constituted the core was not an easy task. Additionally, the teachers could not reach an agreement on whether to mark the core in the textbook itself or in the teacher guide; they felt that the former makes it easier to use whereas the latter reflects a greater respect for the teacher's autonomy. In spite of these disagreements, the teachers managed to mark what they perceived as the core in a considerable part of the textbook.

Another organizing tool on which the teachers worked involved adding informative titles to textbook units and lessons. The textbook that the teachers edited comprised 31 units; each unit was organized as a series of two to six lessons. The titles of the units and lessons typically provided information about the mathematical topic of the unit and the lesson (respectively), for example, "Substituting numbers into algebraic expressions." However, in a small number of cases this was not the case, and either no information regarding the mathematical content was revealed by the title or it was too similar to titles of other lessons or units. Several teachers thought that it was important for the titles of the lessons and the units to provide information about the mathematical content included in them, and decided to edit the titles whenever they were not sufficiently informative. The goal was to enable the reader (teacher, student, or parent) to grasp the mathematical topic of the lesson or the unit just from the title, without having to delve into the whole text.

The fourth organizing tool on which the teachers worked involved making practice exercises easily accessible. The textbook the teachers edited contained several sets of exercises intended for practicing previously taught materials. These sets of practice exercises were placed at the end of several units, and no indication about them was given in the table of contents or anywhere else in the textbook. The teachers felt that the practice exercises were useful, and decided to make them more easily accessible for the teachers who use the textbook. To this end, they created a table of contents for all the sets of practice exercises.

4 Addressing Students' Difficulties: Mathematical Modifications

In a follow-up study (Gottlieb, 2016), we continued to analyze the changes that the M-TET teachers suggested making in the textbook they used in class. However, this time we did not examine these changes through the lens of the teachers' goals, as described in the previous section. Instead, we focused on the changes the teachers suggested through the lens of the resulting mathematics offered to students. The analysis focused on a central topic in the seventh grade mathematics curriculum, namely, equivalent algebraic expressions. Analysis of the changes that the teachers who participated in the third year of M-TET suggested in a key unit on this topic revealed – as noted also in the previous case – that these changes altered, to some extent, the mathematics offered to students. This is elaborated and exemplified below.

The textbook units on the topic of equivalence of algebraic expressions included an extensive use of two algebraic activities. One is manipulating expressions using properties of real numbers (i.e., simplifying and expanding expressions), which typically serves as a principal means for generating, maintaining, or proving equivalence of algebraic expressions. For instance, the distributive property is useful for proving that the expression $5(a + 2)$ is equivalent to the expression $5a + 10$.

The other algebraic activity used in the textbook units on the topic of equivalence of algebraic expressions was substitution of numerical values into expressions. This algebraic activity typically serves as a principal means for proving non-equivalence of algebraic expressions. For example, substituting a numerical value (e.g., 3) into the expressions $5(a + 2)$ and $5a + 2$ is useful for proving that the two expressions are not equivalent because it produces different numerical outcomes (25 and 17, respectively).

A problem that students frequently encounter when they try to generate expressions that are equivalent to a given expression is that, as a result of making mistakes when manipulating the given expression, they end up with expressions that are not equivalent to the given expression. For example, if when trying to find expressions that are equivalent to the expression $1 + 6(x + 3) + 2x$ students erroneously add 1 and 6 before performing the distributive property on $6(x + 3)$, the resulting expression would be $7x + 21 + 2x$, which is not equivalent to the original expression $1 + 6(x + 3) + 2x$. This problem was encountered by students of one of the participating teachers and she raised it for discussion with the group of teachers.

The participating teachers felt that the textbook does not provide students with tools that would enable them to check their answers and detect whether the expressions they produce are indeed equivalent to a given expression. To address this deficiency, the teachers proposed to add in relevant places of the textbook explicit requests for students to check their answers by substituting numerical values into the expressions they produced – a method that was not part of the original textbook approach, which restricted the use of substitution to proving non-equivalence and not for checking equivalence. Most teachers supported this proposal. Eventually, they added, in a considerable number of places in the textbook they edited, the use of substituting several numerical values into algebraic expressions as a means of assisting students with examining the potential of the expressions they constructed to be equivalent to a given expression.

This kind of use of substituting numerical values into expressions (i.e., for examining the potential of algebraic expressions to be equivalent) seldom appears in textbooks or in the scholarly literature (Ayalon & Even, 2014; Pilet, 2013). Moreover, encouraging such use might be pedagogically problematic. Research suggests that students often erroneously use the method of checking a number of examples for proving mathematical claims (e.g., Harel & Sowder, 2007). In particular, students tend to use substitution of numerical values into expressions for proving that two given expressions are equivalent (Ayalon & Even, 2014). Thus, asking students to use this method for checking the potential for equivalence – as the M-TET teachers intended – could enhance the mathematically invalid use of this method for justifying equivalence.

This potential risk was raised by one of the teachers. She explained to her colleagues that instructing students to use substitution for checking equivalence could lead them to mistakenly conclude that substitution is a suitable method for proving equivalence. However, the teachers had no follow-up discussion regarding this undesired potential outcome.

5 Connections Between Mathematics Teachers and Textbook Authors

As explicated earlier, the voice of the community of mathematics teachers regarding textbooks is seldom heard. Thus, teachers' aspirations about desired textbooks generally remain unknown to curriculum developers and textbook writers, and teachers rarely influence textbook design. Moreover, the interactions between mathematics teachers and textbook authors are often in the form of professional development activities initiated and led by textbook authors, whereas the teachers are typically in a position that does not enable them to make decisions regarding the content and format of their interactions with textbook authors. As a result, conventional connections between mathematics teachers and textbook authors are limited and mainly unidirectional – originating from textbook authors and proceeding to teachers.

Two studies in the M-TET research program (Even & Olsher, 2014; Even et al., 2016) revealed that the M-TET work environment has the potential to create an authentic setting for establishing novel connections between teachers and textbook authors. Throughout the years of the project's operation the participating teachers took advantage of being able to consult with the textbook authors to inquire about various choices they made in the textbook and to discuss with them potential modifications the teachers felt were desirable. This is illustrated below using the editing work that took place during the second year of the project on the Pythagorean

Theorem unit. This unit was included in the experimental version of an 8th grade textbook, which was approved by the Ministry of Education for students in the lower one-third achievement level (more details about this example can be found in Even et al., 2016).

Two central issues were the focus of the teachers' deliberations when editing the textbook unit on the Pythagorean Theorem. One issue was related to the way the textbook introduces the Pythagorean Theorem; the other to the way it justifies it. As part of their editing work the teachers invited the author of this textbook unit to discuss with her their dilemmas and proposals. The interactions between the teachers and the textbook author are described below.

The first issue about which the teachers were debating was the way that the textbook introduces the Pythagorean Theorem. The Pythagorean Theorem describes a fundamental unanticipated relation involving the three sides of a right triangle: the square of the hypotenuse (c) is equal to the sum of the squares of the other two sides (a and b), or $a^2 + b^2 = c^2$. The Pythagorean Theorem textbook unit begins by presenting students with a hypothetical student's false claim about the connections between the lengths of the sides of right triangles ($a \cdot a = b + c$) accompanied by a few triangles for which the claim is true, asking students to determine whether the claim is true for all right triangles. Some of the teachers in the group were concerned that if the false statement was introduced before the Pythagorean Theorem was stated, the students would consider it as true. These teachers then proposed to revise the introductory part of the textbook unit. Other teachers in the group supported the textbook approach, arguing that an effective way to deal with students' mistakes is to purposely examine a false statement that initially appears to be true.

Another issue on which the teachers focused when examining the textbook presentation of the Pythagorean Theorem was the way that the textbook addresses its justification, namely, that it relies only on checking a few examples. Moreover, the textbook explicitly suggests this approach as a legitimate means of checking whether a mathematical claim is true. This time there was a consensus among the teachers that the textbook approach was mathematically problematic. However, they were not sure how to modify it. The teachers then decided to invite the author of the textbook unit on the Pythagorean Theorem to the following face-to-face monthly meeting so that they could better understand her rationale and point of view when she was writing the Pythagorean Theorem unit.

When they met with the author of the textbook unit, the teachers first presented their contrasting approaches regarding whether to begin teaching the Pythagorean Theorem with a false statement. The author responded by explaining the potential she saw in such an introduction to create a feeling of surprise that the Pythagorean Theorem is true, which probably would not be created if it was just straightforwardly presented to students. Such a feeling of surprise, she explained, has the potential to evoke in students the need to justify that the Pythagorean Theorem is true in order to be convinced that this surprising relation involving the three sides of a right triangle is indeed true.

Moreover, the author maintained that because the false claim she included in the introduction is true for some right triangles but not for others, the activity she designed demonstrates to students that in mathematics one should not assume that if a particular statement is true for some cases it would always be true. Thus, the activity has the potential to encourage students to refrain from relying on checking examples as a means of generalizing and justifying a mathematical statement – known to be students' preferred way to form and test mathematical conjectures (e.g., Harel & Sowder, 2007) – but instead, to look for mathematically acceptable ways of justification.

This account of the author regarding the rationale underlying her design of the introductory part of the Pythagorean Theorem unit served as a starting point for the next stage of the conversation, which shifted to focus on the other problem that the teachers identified with the textbook approach. The teachers argued that, as the author just explained, when the Pythagorean Theorem is introduced, the textbook demonstrates to students that the method of checking a few examples is not a legitimate method for verifying that a mathematical statement is true. However, it turns out that the textbook suggests the very same method of checking a few examples as a legitimate method for verifying that the Pythagorean Theorem is true. The author agreed with the teachers that there was a problem in the textbook, supported the teachers' suggestion to add in the textbook a proof of the Pythagorean Theorem, and promised to think about making the change when revising the textbook. And indeed, when preparing a revised version of the textbook, the author added a proof of the theorem, as the teachers had suggested. (Eventually, however, the beginning of the lesson and the proof were omitted in the final version of the textbook as a result of the process of approval by the Ministry of Education.)

It is worth noting that making changes in textbooks written by expert curriculum developers was a role that not all teachers who participated in the M-TET project easily embraced. In our research (Even & Olsher, 2014) we found that respect for the decisions and choices of the textbooks' authors caused some of the teachers to refrain from making changes in the textbooks. For example, in response to a significant change proposed by some teachers during the first year of the project, another teacher suggested not to introduce such a major change because: "There are professional people who wrote the book with a broader and more secure view". Similarly, on a different occasion a teacher responded to a proposal for change by other teachers, saying: "I think that if they [the textbook authors] decided to include it … then it is probably important." Likewise, some teachers tended to describe proposals for change, but refrained from actually modifying the textbook, explaining that it is the textbook authors who have the expertise to decide whether these ideas were worthy to enact.

6 Connections Between Mathematics Teachers and Mathematicians

Conventional connections between secondary school teachers and university mathematicians occur – if at all – mainly during the stage of teacher preparation. At this stage, in many countries, prospective secondary school teachers study advanced mathematics in academic courses taught by mathematicians (Tatto, Lerman, & Novotna, 2009, 2010). In contrast, at the stage of working at school, professional development courses and workshops for practicing mathematics teachers are usually designed and conducted by mathematics educators, and not by university professors whose main activity is mathematical research (there are a few exceptions, of course).

Consequently, connections between teachers and research mathematicians – the experts on the discipline of mathematics – are extremely limited and infrequent. They occur before teachers start teaching at school, focus on academic mathematics, and, similar to the nature of conventional interactions of mathematics teachers and textbook authors, it is the mathematicians – and not the prospective teachers – who make the decisions regarding the content and format of their interactions with the (prospective) teachers. Hence, teachers rarely have opportunities to interact with mathematicians during their teaching career and to consult with them about the mathematics they teach in class.

Our research (Even et al., 2016) showed that the M-TET work environment has the potential to create an authentic setting for establishing novel connections not only between teachers and textbook authors, but also between teachers and university mathematicians. Throughout the years of the project's operation the participating teachers used the opportunity to consult with a mathematician to inquire about various issues and to discuss with him potential modifications they considered making in the textbooks they edited.

For example, in the case of editing the unit on the Pythagorean Theorem described before, after the textbook author supported their suggestion to add a proof to the Pythagorean Theorem in the textbook, the teachers decided to do so. At first they decided to adopt a proof that appeared in another textbook, which is based on a visual demonstration accompanied by a full deductive proof. However, the teachers felt that a deductive proof would be too difficult for students in the lower one-third achievement level for which the textbook they were editing was intended. However, they were not sure whether the informal visual demonstration without the deductive proof could be considered as a legitimate mathematical proof.

The teachers then decided to invite the mathematician made available to them for consultation to a face-to-face monthly meeting and to consult with him their idea about adding a proof to the Pythagorean Theorem. The mathematician supported the teachers' decision to add a proof to the Pythagorean Theorem. He also shared with them the important role that proof has in his own everyday mathematical work as a research mathematician. However, he stressed that it is the teachers, and not him, that have the expertise needed to decide whether adding a proof at the stage where the particular group of students are was appropriate, and if so, which kind should be added. After meeting with the mathematician, the teachers decided to add to the textbook both a formal deductive proof and an informal visual demonstration. They suggested that in this way, teachers would be able to choose to use in class whatever best suits the level of the students in class.

Interestingly, the participating teachers used the availability of a mathematician for consultation to discuss with him not only mathematical aspects but sometimes also didactical issues (Even & Olsher, 2014). For example, the teachers who participated in the first year of the project consulted with the mathematician about an issue regarding which of two textbook problems he thought was more difficult for students, and whether a certain mathematical definition should be included in the textbook. In such cases, as was illustrated in the case of the Pythagorean Theorem, the mathematician tended to stress that it is the teachers who are the didactical experts and they know best what suits students at different ages and achievement levels.

7 Conclusion

In many countries the prevalent views and assumptions about the mathematics teacher's role typically regard mathematics teachers as curriculum enactors and users of textbooks produced by expert curriculum developers and textbook writers. This view of the teachers' role is reflected in research on the relationships between teachers and textbooks, which typically focuses on how textbooks influence classroom instruction and how teachers use curriculum materials (e.g., Eisenmann & Even, 2011; Haggarty & Pepin, 2002; Remillard, Herbel-Eisenmann, & Lloyd, 2009; Stein, Remillard, & Smith, 2007; Thompson & Senk, 2014).

The M-TET project attempted to fundamentally alter this current state of affairs by inviting mathematics teachers to collaborate in editing the textbooks they use in their classrooms. The chapter examined potential opportunities and challenges associated with giving teachers the opportunity to edit the textbooks they use in the unique M-TET work environment, whose characteristics are usually not part of teachers' ordinary practice. This included producing a textbook by making changes in a textbook designed by expert curriculum developers, designing a textbook for a broad student population instead of focusing on the specific student population taught, collaborating with members of the extended community of mathematics teachers in order to produce an agreed upon professional outcome, and consulting with professionals who are not part of the teachers' usual milieu: textbook authors and mathematicians.

As illustrated in this chapter, the setting of the M-TET project enables a rare opportunity whereby researchers, textbook authors and policy makers could learn about teachers' needs, desires, and aspirations regarding textbooks. The fact that when using a textbook in class, teachers often make changes in the proposed mathematical content and in the approaches to teaching and learning suggested in the textbook is not surprising and has been documented by empirical research that examined curriculum enactment (e.g., Brousseau, 1997; Drake & Sherin, 2006; Eisenmann & Even, 2011; Even & Kvatinsky, 2010; Tarr et al., 2006). However, the changes that teachers make when using textbooks in class are often not based on deliberate and thoughtful considerations (e.g., Leshota & Adler, 2014) nor do they reflect the changes teachers make or desire, which are not related to contents or to teaching approaches. Thus, this line of research provides limited information regarding the changes that teachers wittingly and purposely would choose to make in textbooks.

The unique setting of the M-TET project, which addresses the shortcomings of research that focuses on curriculum enactment and classroom use of textbook, enabled us to identify and characterize a type of change that is geared at making the textbook more user-friendly by creating organizing tools embedded in the textbook. This type of change has not been previously reported in the literature, which comprises only reports on changes in the mathematical content or in the approaches suggested for teaching mathematical content.

Additionally, the M-TET setting enabled us to detect challenges that teachers might encounter when they attempt to accommodate the textbook they use to fit their needs and preferences. The challenges demonstrated in this chapter were associated with conceptual aspects of mathematics teaching and learning. Such challenges occurred, for example, when the teachers strived to determine what constitutes the textbook core (what should be considered as core), or when they worked on categorizing the highlighted textbook contents in order to make them easily accessible (what categories should be chosen). (Detailed information on professional, conceptual, and technical challenges that the M-TET teachers faced when they collaborated on making changes in textbooks can be found in Olsher & Even, 2018.)

As was demonstrated in this chapter, changes that teachers suggest making in textbooks might result (either intentionally or unintentionally) in a low level of fidelity of implementing some aspects of the intended (written) curriculum; sometimes with some alterations in the mathematics offered to students. This can be illustrated by the end result of the process of addressing the challenge that the teachers encountered when they worked on making the highlighted textbook contents easily accessible. As shown, the M-TET teachers' solution underscored the separation of mathematical strands (algebra and geometry). Thus, the resulting edited textbook strengthened the portrayal of the discipline of mathematics as a collection of separate domains; as if algebra and geometry, for instance, are unrelated. Such portrayal of the discipline was in contrast to the textbook approach and the national curriculum (Ministry of Education, 2009, 2013) that emphasize integration and connections among different mathematical strands. It is also in opposition to current approaches in mathematics education including mathematicians' views on the characteristics of the nature of mathematics, which are important to teach teachers (Hoffman & Even, 2018).

Another example of an alteration of the mathematics offered to students is the novel use of the method of substituting numerical values into expressions that the M-TET teachers added to the textbook they had edited. Whereas the original textbook presented this method as a useful means only for proving non-equivalence of algebraic expressions, the edited textbook introduced an additional role for the method of substituting numerical values into expressions, and presented it as useful both for proving non-equivalence and for examining the potential of algebraic expressions to be equivalent. The need for a tool for the latter emerged from the teachers' reflections on their classroom teaching experience and their recognition that such a tool did not previously exist in the textbook.

Although the method of substituting numerical values into expressions could assist in examining the potential of algebraic expressions to be equivalent (Ayalon & Even, 2014), research suggests that teaching students to use this method for checking the potential of the expressions to be equivalent might enhance students' tendency to erroneously use this method to prove equivalence (Ayalon & Even, 2014; Smith & Phillips, 2000). The prospect for this unintentional undesirable outcome is also supported by research findings that show that inductive reasoning (generalizing from a pattern or observations made in specific cases) – in contrast to deductive reasoning (logically inferring conclusions from known information) – is often students' preferred way to test mathematical conjectures (Harel & Sowder, 2007). Thus, while attempting to address students' difficulties, the resulting edited textbook that the M-TET teachers produced appeared to strengthen the portrayal of a mathematically invalid method as being valid.

Interestingly, the same problem of using the method of checking a few examples as a means of proving a mathematical claim also emerged when the M-TET teachers worked on editing the Pythagorean Theorem unit. This time, however, it was the original textbook that suggested the use of this method, although the teachers criticized such a use. Moreover, when the teachers discussed their criticism with the textbook's author, she agreed with them that there was a problem with the textbook because it portrays the checking of a few examples as a legitimate method for verifying that the Pythagorean Theorem is true. The textbook's author also supported the teachers' suggestion to add to the textbook a proof to the Pythagorean Theorem, and when preparing a revised version of the textbook, she indeed added a proof of the theorem, as the teachers had suggested.

As was demonstrated in the above episode, the M-TET setting contributed to creating an atmosphere whereby teachers' ideas could be confidently presented and discussed with textbooks authors. Moreover, in contrast to common practice, most of the interactions between teachers and textbook authors in the M-TET work environment were initiated by the teachers themselves, who were also the ones who determined the content, timing, and format of these interactions, based on their needs and goals. In this way, the M-TET work environment facilitated interactions in which the teachers and textbook authors have more equal positions and authority. As in traditional interactions, in the M-TET work environment the teachers had opportunities to learn from the textbook authors about their intentions and ideas (e.g., the inclusion of false claims in textbooks). However, such learning occurred on the teachers' terms. Moreover, teachers had opportunities to deliberate with textbook authors their ideas and principles related to the teaching of mathematics, and to influence textbook design (e.g., a missing proof).

In contrast to common practice, the M-TET work environment also facilitated interactions in which teachers and research mathematicians discussed issues that are of interest to the teachers and are authentic to their teaching practice (e.g., aspects of mathematical proofs). The M-TET environment provided teachers with opportunities to increase their confidence (e.g., the essential role of proofs), and to improve their understanding of what mathematics actually is by hearing first hand from an active research mathematician about the nature of the work he engages in as part of his everyday professional life. Similarly to the interactions between the teachers and textbook authors, the interactions between the teachers and the mathematician in the M-TET work environment were initiated by the teachers themselves, who were also the ones who determined the content, timing, and format of these interactions, based on their needs and goals.

As demonstrated in this chapter, giving teachers the opportunity to edit the textbooks they use in their classrooms might result in a low level of fidelity of implementing the intended (written) curriculum and in didactically problematic presentations of mathematical ideas. However, as shown, working with colleagues in designing a textbook for a broad student population facilitated the development, clarification, and articulation of ideas regarding the teaching of mathematics, which could then be confidently presented and discussed with textbook authors and mathematicians. Thus, by enabling the transformation of conventional connections of teachers with textbook authors and with mathematicians, the unique characteristics of the M-TET work environment provided opportunities to address potential shortcomings of the outcomes of teachers' textbook editing.

Such connections with teacher colleagues, textbook authors, and mathematicians were well appreciated by the M-TET teachers, as is illustrated by the following excerpts from interviews with two M-TET teachers. The first excerpt illustrates how participation in the M-TET project contributed to teachers' professional development and the building of a professional community of teachers.

> I feel that I am in a continuous process of growth. The project empowers me, being part of a group who works together on something important … The ability and the motivation to test my intentions all the time, not to surrender to the routine assignments of teaching, but instead, to stop, to analyze the lesson and the tasks, to reflect on the lesson and to consider a change … The interactions with the other teachers … listening, talking, and sometimes even arguing with other teachers, learning from different people having different opinions—this is all part of me now. It is difficult for me to think of myself, who I was had I not been here.

The following excerpt describes how interactions (which the teacher termed collaborations) with the textbook authors and the mathematician in the M-TET environment contributed to the teachers' professional identity and classroom teaching.

> The talks, the collaboration with the authors and the mathematician, there are not such things anywhere. It makes me feel important that they want to listen to me and to work with me. They talk to me at eye level … It changed the way I see myself and the way I use the curriculum in class. I now ask myself: What is the aim of this task? What would the author say about this part of the lesson? Is the mathematical concept in this lesson used correctly?

This chapter addressed the question: What might be gained and what might the challenges be if the community of mathematics teachers is given an opportunity to participate in textbook development? The potential gains and challenges described in this chapter laid the groundwork for follow-up studies by revealing new research questions that are important to pursue. For example, what changes would teachers make in the textbook they use in class if given the opportunity to do so? How might these changes impact the teaching and learning of mathematics? How might the conventional connections between teachers and other professionals (textbook authors, mathematicians, and researchers) be transformed on a large-scale basis to enable more equal positions and authority for teachers, and increase teacher agency?

References

Ayalon, M., & Even, R. (2014). Students' opportunities to engage in transformational algebraic activity in different beginning algebra topics and classes. *International Journal of Science and Mathematics Education, 13*(Suppl 2), S285–S307.

Brousseau, G. (1997). *Theory of didactical situations in mathematics*. Dordrecht, The Netherlands: Kluwer.

Drake, C., & Sherin, M. G. (2006). Practicing change: Curriculum adaptation and teacher narrative in the context of mathematics education reform. *Curriculum Inquiry, 36*(2), 153–187.

Eisenmann, T., & Even, R. (2011). Enacted types of algebraic activity in different classes taught by the same teacher. *International Journal of Science and Mathematics Education, 9*, 867–891.

Even, R., Ayalon, M., & Olsher, S. (2016). Teachers editing textbooks: Transforming conventional connections among teachers, textbook authors, and mathematicians. In M. Phakeng & S. Lerman (Eds.), *Mathematics education in a context of inequity, poverty and language diversity: Giving direction and advancing the field* (pp. 127–140). Dordrecht, The Netherlands/Heidelberg, Germany/New York, NY/London, UK: Springer.

Even, R., & Kvatinsky, T. (2010). What mathematics do teachers with contrasting teaching approaches address in probability lessons? *Educational Studies in Mathematics, 74*, 207–222.

Even, R., & Olsher, S. (2014). Teachers as participants in textbook development: The integrated mathematics wiki-book project. In L. Yeping & G. Lappan (Eds.), *Mathematics curriculum in school education* (pp. 333–350). Dordrecht, The Netherlands/Heidelberg, Germany/New York, NY/London, UK: Springer.

Friedlander, A., Even, R., & Robinson, N. (2018). Designing mathematics textbooks: The case of the integrated mathematics curriculum program. In N. Movshovitz-Hadar (Ed.), *K-12 mathematics education in Israel: Issues and challenges. Series on mathematics education: Volume 13* (pp. 209–216). Singapore, Singapore: World Scientific Publication. ISBN: 978-981-3231-18-4.

Gottlieb, A. (2016). *Changes suggested by teachers in the textbook they use in class: The case of equivalent algebraic expressions*. Master thesis, Weizmann Institute of Science (in Hebrew).

Haggarty, L., & Pepin, B. (2002). An investigation of mathematics textbooks and their use in English, French and German classrooms: Who gets an opportunity to learn what? *British Educational Research Journal, 28*(4), 567–590.

Harel, G., & Sowder, L. (2007). Toward a comprehensive perspective on proof. In F. K. Lester (Ed.), *Second handbook of research on mathematics teaching and learning: A project of the National Council of teachers of mathematics* (pp. 805–842). Charlotte, NC: Information Age.

Hoffmann, A. & Even, R. (2018). What do mathematicians wish to teach teachers in secondary school about mathematics? In E. Bergqvist, M. Österholm, C. Granberg, & L. Sumpter (Eds.), *Proceedings of the 42nd Conference of the International Group for the Psychology of Mathematics Education* (Vol. 3, pp. 99–106). Umeå, Sweden: PME.

Leshota, M., & Adler, J. (2014). The analysis of teachers' mobilisation of the textbook. In K. Jones, C. Bokhove, G. Howson, & L. Fan (Eds.), *Proceedings of the international conference on mathematics textbook research and development (ICMT-2014)* (pp. 291–296). Southampton, GB: University of Southampton.

Ministry of Education. (2009). *Mathematics curriculum for grades 7–9*. Jerusalem, Israel: Author. (Hebrew).

Ministry of Education. (2013). *General introduction to the junior high-school mathematics curriculum*. (Hebrew). Retrieved from http://meyda.education.gov.il/files/Mazkirut_Pedagogit/matematika/mavo.pdf

Olsher, S., & Even, R. (2018). Organizing tools suggested by teachers in the mathematics textbook they use in class. *International Journal of Science and Mathematics Education*, https://doi.org/10.1007/s10763-018-9902-2.

Pilet, J. (2013). Implicit learning in the teaching of algebra: Designing a task to address the equivalence of expressions. In B. Ubuz, C. Haser, & M. A. Mariotti (Eds.), *Proceedings of the 8th congress of the European Society for Research in mathematics education* (pp. 510–519). Ankara, Turkey: Middle East Technical University and ERME.

Remillard, J. T., Herbel-Eisenmann, B. A., & Lloyd, G. M. (Eds.). (2009). *Mathematics teachers at work: Connecting curriculum materials and classroom instruction* (pp. 152–170). New York, NY: Routledge.

Smith, J. P., & Phillips, E. A. (2000). Listening to middle school students' algebraic thinking. *Mathematics Teaching in the Middle School, 6*, 156–161.

Stein, M. K., Remillard, J., & Smith, M. S. (2007). How curriculum influences student learning. In F. K. Lester (Ed.), *Second handbook of research on mathematics teaching and learning* (pp. 319–369). Charlotte, NC: Information Age.

Tarr, J. E., Chavez, O., Reys, R. E., & Reys, B. J. (2006). From the written to the enacted curricula: The intermediary role of middle school mathematics teachers in shaping students' opportunity to learn. *School Science and Mathematics, 106*, 191–201.

Tatto, M. T., Lerman, S., & Novotna, J. (2009). Overview of teacher education systems around the world. In R. Even & D. L. Ball (Eds.), *The professional education and development of teachers of mathematics: The 15th ICMI study* (pp. 15–24). New York, NY: Springer.

Tatto, M. T., Lerman, S., & Novotna, J. (2010). The organization of the mathematics preparation and development of teachers: A report from the ICMI study 15. *Journal of Mathematics Teacher Education, 13*, 313–324.

Thompson, D. R., & Senk, S. L. (2014). The same geometry textbook does not mean the same classroom enactment. *ZDM-The International Journal on Mathematics Education, 46*(5), 781–795.

Ruhama Even Professor at the Weizmann Institute of Science and holds the Rudy Bruner Professorial Chair of Science Teaching. Her main research and development work is structured around three interrelated foci: (a) the professional education and development of mathematics teachers, (b) mathematics curriculum development and analysis, and (c) the interplay of factors involved in shaping students' opportunities to learn mathematics. She is the head of the Integrated Mathematics (Matematica Meshulevet) curriculum development program, the MesiMatica formative assessment project, and the M-TET (Mathematics Teachers Edit Textbooks) project, and was a member of the Professional National (Israeli) Committee of School Mathematics. Ruhama Even has been co-chair of ICMI Study 15 on the professional education and development of teachers of mathematics, and she serves as an editorial board member of the Journal of Mathematics Teacher Education (JMTE), Mathematics Education Research Journal (MERJ), and the Encyclopedia of Mathematics Education of which she is also a section editor.

Discussion: Teacher Learning in Community: Premises, Promises and Challenges

Lily Orland-Barak

1 Teacher Learning in Community

In his account of how cardiac surgeons and their teams worked together as they took on a new technique in the operation room, Atul Gawande, a general surgeon and author of "*Complications: A surgeon's notes on an imperfect science*" (2002), writes:

> … what's most important to [surgeons] is finding people who are conscientious, industrious, and boneheaded enough to stick at practicing this one difficult thing day and night for years on end (p. 19) … Everyone had new tasks, new instruments, new ways that things could go wrong, and new ways to fix them. As you'd expect, everyone was found to experience a substantial learning curve …. Practice, it turned out, did not necessarily make perfect. Whether it did … depended on *how* the surgeons and their teams practiced. (p. 29, italics in original)

Although in the context of professional education in Medicine, Gawande's account seems to resonate strongly with the accounts of how teachers collaborated in the Math teaching inquiry communities presented in the two papers of this section. Both Martinovic and Horn-Olivito and Even's studies highlight similar conditions that need to be met in order for the work of teachers and teaching to align with the challenges of learning in an era of change. One is the value of learning when professionals collaborate as a community of practice characterized by distributed expertise, to explore emergent problems of practice within their own settings. Furthermore, when they develop together creative ways of tackling these problems through systematic inquiry, with a sense of commitment, agency and accountability towards their profession. These conditions seem to cross professional and disciplinary boundaries, as well as geographical boundaries within the same domain, as is the case of the two papers dealing with Mathematics teaching and teacher learning in Canada and in Israel.

L. Orland-Barak (✉)
The University of Haifa, Haifa, Israel
e-mail: lilyb@edu.haifa.ac.il

Y. Ben-David Kolikant et al. (eds.), *STEM Teachers and Teaching in the Digital Era*, https://doi.org/10.1007/978-3-030-29396-3_4

The longitudinal study of Dragana Martinovic and Heidi Horn-Olivito, as the authors write, acknowledges teachers as holders of contextualized and practitioner knowledge, and presents an example of a successful collaboration between two educational organizations, which developed into a province-wide project of a Mathematics Leadership Community of Practice. The school-university partnerships that the authors led and developed in the context of the large scale project, underscore the value of engaging Math educators in inquiry projects through school-university collaborations with professionals from different domains and levels of expertise. Such inquiry projects involve both pre-service and in-service professional learning (distributed expertise). They also promoted research-engaged schools whereby teachers become learners of their own contexts (systematic inquiry into local problems of practice). The project also considered data from a view of agency, responsibility, and confidence to teach and lead longitudinal data collection (professional accountability and collective teacher efficacy).

The creation of the partnerships is also directed by the importance attributed to promoting new roles for teachers as facilitators and school leaders, thus, enhancing their professional image and their sense of commitment and agency towards their profession. Indeed, the authors allude to these conditions contending that a school culture that supports different forms of teacher inquiry creates a professional environment that is evidence-based and can lead to curricular innovations that grow out of systematic research into teachers' idiosyncratic, local practices. Building on Wilkins' characteristics for such a school culture to succeed (Wilkins, 2011 p. 9), they assert that

> … in order for this to happen, educators need … to have a sense of permission to work differently, granted by the school's leadership team; a sense of support from the organization and the wider system, such as providing conditions for staff to engage in research, focusing on research-related professional development (PD), involving in collaborative networks run by universities; and a sense that success will be marked by recognition in desirable ways … by creating opportunities for educators to present their work at conferences or similar knowledge dissemination venues. (ibid.)

An important aspect stressed in the paper is that for schools to build such a culture of learning and use of data to inform their decisions (such as related to assessment, school climate, and behavioral and regular classroom data), teachers must be educated accordingly and appropriately for such a task. Such kind of training, the authors rightly contend, is not typically part of formal teacher education curricula. One of the main goals of the Collaborative Inquiry (CI) framework described in the paper is, thus, preparing teachers for handling such skills:

> This project was the foundation for our current work in supporting a distributive mathematics leadership model. Our years of supporting CI projects helped to create the conditions for which teachers were primed to emerge as leaders and researchers, ready to tackle the challenge of mathematics reform. (ibid.)

Even's study is grounded in similar conditions that foster professional learning in the context of Mathematics teachers editing textbooks. Her study highlights the value of creating opportunities for working with colleagues, and articulating and clarifying ideas in a professional community designed around productive connections between teachers, authors, and mathematicians. Positioning the project as a ground-breaking arena of inquiry within teachers' work environment, Even's teachers are encouraged to function as curriculum developers of the textbooks that they use (exploring emergent problems of practice within their own settings), working in collaboration with other teachers, professionals, and academics. Professionals, such as textbook authors and mathematicians are not part of the teachers' usual milieu. Such distributed expertise empowers teachers to articulate their interpretations and understandings of how textbooks need to be adapted to meet the authentic needs and profiles of their schools and classrooms. In doing so, Even argues, the M-TET work environment can transform the conventional connections of teachers with textbook authors and with mathematicians (empowering teachers and engaging them with a sense of commitment, agency and accountability towards their profession). Even stresses these conditions throughout the paper, contending that:

> … the voice of the community of mathematics teachers regarding textbooks is seldom heard. Thus, teachers' aspirations about desired textbooks generally remain unknown to curriculum developers and textbook writers, and teachers rarely influence textbook design. Moreover, the interactions between mathematics teachers and textbook authors are often in the form of professional development activities initiated and led by textbook authors, whereas the teachers are typically in a position that does not enable them to make decisions regarding the content and format of their interactions with textbook authors. As a result, conventional connections between mathematics teachers and textbook authors are limited and mainly unidirectional-originating from textbook authors and proceeding to teachers. (ibid.)

Conceptually, the two studies draw on the assumption that learning is best understood as actions and activities integrated in a complexity of institutional and historical practices. In this respect, Even makes a strong case for the uniqueness of the project in that it addresses the crucial need to begin creating relevant channels of communication in Mathematics teaching between academic/disciplinary content knowledge (formally recognized as owned by researchers and academics) and professional/pedagogical content knowledge (owned by teachers). These two domains of knowledge have been historically divided and separated in the structure of mainstream professional schools in Higher Education institutions, leading to the fragmentation of knowledge in the preparation of future teachers. Becher's recent study entitled, *Dynamics of Knowledge Supply and Demand between University and Workplace Bodies in Professional Education Curricula: The Cases of Teaching and Social Work*, presents an insightful scholarly thesis on the issue. The author contends that the patterns of thought instituted traditionally by the university, frame experience in a highly general, analytical manner, and marginalize concerns with particularities and with engaged knowledge in action. Thus, universities tend to adopt analytic modes of instruction, stressing rational over practical, particularistic modes of thinking, often marginalizing the acquisition of professional competence as a genuine and valid goal of university higher education. It follows that university training tends to emphasize the acquisition of formal knowledge, often abstracted from context and particularity, and applicable to practice through prescribed, de-contextualized techniques. Paradoxically, Becher continues, we are witnessing a growing demand from the field to define the role of universities not only as providers of general education and disseminators of research, but also as contexts for the accreditation of many professions and vocational occupations. In this context, professional education is in a somewhat problematic position, at the nexus of sponsors (governments and employers), providers (higher education institutions) and clients (students and the public). Such a position holds significant implications for course design and Higher Education curricula, leading to evident divergence between the content of educational programs and the demands of professional work, as reported by first year practitioners. This discontinuity between professional learning in Higher Education and the nature of work is also due to programs' failure to respond to the non-academic, service-oriented nature of working environments. The academic context of professional education (PE), thus, interferes with achieving educational relevance for practice: PE departments/units are influenced by the academic culture which appreciates and enhances scientific knowledge and research over applied service skills; the disciplinary organizational structure of Higher Education institutions serves the scientific priority, but limits curricular integration, so essential to PE; non-integrative standards for assessment fail to recognize deficiencies, both in students and programs. Hence, discontinuity between what universities provide, and what society and practitioners say they need, relies on the teaching culture and ideology at the university, premised on academic excellence. Nonetheless, on the background of growing partnerships between the university and the service-industry for enhancing professional education (such as the exemplary cases in this section), it is reasonable to believe that the historical boundaries between academic and professional education are slowly beginning to break. Even's project, indeed, mends this historical divide and lacuna, creating a professional platform which grants the opportunity for teachers to "collaborat[e] with members of the extended community of mathematics teachers in order to produce an agreed upon professional outcome, and consulting with professionals who are not part of the teachers' usual milieu: textbook authors and mathematicians" (ibid.).

In a similar vein, Martinovic and Horn-Olivito's determination and persistence to pursue their educational vision despite historical divides and political sensitivities influencing district policy making in mathematics teaching and teacher education in Ontario, is pungent in their introductory and background section. As they contend:

> [T]the current reform was accompanied by a more aggressive and highly politicized tone to shift teaching practices (i.e., the media used the language of "national emergency," "Ontario's math problem," and "children at the mercy of the curriculum"). Educators across Ontario were encouraged to develop their mathematical pedagogical-content knowledge… The open nature of CI did not fit the urgency of the mandate or the current reality of what teachers needed to support their growth as mathematics educators. However, we knew that deserting the agency and leadership that had been developed over the years would be a huge step backward. (ibid.)

The above shifts in the orientation to teacher learning in pre- and in-service teacher education, r*espond to public expectations for schools to explore* how teachers can learn to teach in more powerful and demanding ways. These new forms of teacher learning include learning to transform pedagogical and subject matter knowledge into pedagogical content knowledge. They also stress integrating intellectual with logistical aspects of teaching from a multidisciplinary perspective in dynamic, and complex learning environments. Furthermore, they promote learning to reason and manage the multicultural and multiethnic nature of school contexts in an era of mobility, knowledge exchange and immigration. They also reflect a movement from experimental settings or small-scale field trials where the time span of the learning activities is short, to long term investigations in real-life settings and their development over time. Such a view, I think, proposes investing efforts to attend to what really matters to participants as professionals (Tillema & Orland-Barak, 2006). Theoretically, it supports the contention that participants' co-construction of professional knowledge is, to a large extent, initiated and sustained through ongoing, progressive discourse that allows for the development of professional situational understandings while teams interpret and (re)value work-related situations (Edwards, Gilroy, & Hartley, 2002).

2 Putting It All Together: Promises and Challenges

The two studies presented in this chapter constitute exemplary cases of successful implementations of teacher learning in community, reminding us of Gawande's (2002) assertion, at the outset of this chapter, that "… it takes a good team of thoughtful educational researchers and teacher educators to make it work." Indeed, each of the studies offers a full and rich account of the programmatic and contextual aspects that contributed to the success of each of these projects in the context of Mathematics teacher professional learning. Furthermore, as elaborated above, the studies tell us a lot about the conditions and challenges of sustaining a successful community of practice. In addition, they evidence the importance of having a creative basis and vision on the part of the developers, and of establishing a reciprocal basis of dialogue for extended perspectives to develop, alongside an internal basis of commitment and accountability, sustained and supported by an external organizing framework (Orland-Barak, 2007).

Both studies underscore the value of creating school learning environments for sustaining such kind of dialogic, inquiry-based collaboration. Defined as the interplay between physical conditions and the interpersonal social interactions that promote learning opportunities (Smith, Smith, & DeLisi, 2001), a learning environment can be conducive to the exploration of similarities and differences among views and standpoints, and encourage participants to confront ideas and beliefs, examine the pros and cons of their perspectives, be exposed to alternative perspectives, and engage in suggestions for alternative behaviors which can be implemented in practice (Clark, 2001; Lewis & Ketter, 2004). Productive professional discourse is, thus, sensitive to conflicts that arise from differences of opinion, as opportunities for reconstructing relationships and understandings, potentially leading, in many cases, to conceptual change and to the development of what is often referred to as 'collective knowledge' (Engeström, Engeström, & Suntio, 2002). Such collective knowledge seems to have been fostered in both cases. Specifically, in Even's case, collective knowledge was fostered in the collaborative community of distributed expertise when trying to accommodate the textbook teachers use to fit their needs and preferences in mathematics teaching and learning.

3 Putting It All Together: Challenges

Collective knowledge is also encouraged when the discourse is sustained by certain norms of behavior within the group such as shared responsibility, commitment to the process and a relationship of trust, respect and equality among the participants (Timperley, 2001). These aspects of the discourse are known to be promoted through the various mediating roles that the mentor adopts during the discourse (Orland-Barak, 2014). For example, providing the right 'dose' of challenge and support (Daloz, 1999); encouraging connections between different kinds of knowledge (Gore, Griffiths, & Ladwig, 2004), and challenging teachers to critically explore their taken-for-granted assumptions about teaching and learning, etc. (Wang & Odell, 2002) is essential for the quality of professional discourse that develops in community. Thus, the kind of learning environments that develop within a learning community is strongly shaped by the professional discourse, mentors' roles and the power relations that develop (Edmondson, 2003; Eteläpelto, Littleton, Lahti, & Wirtanen, 2005; Feiman-Nemser & Carver, 2012). These three aspects are only partially attended in the two projects reported, and further attention to these directions in the context of each study is needed. The two chapters propose future lines of investigation in important areas but do not consider the above mentioned foci. For example, Even's discussion underscores the potential gains and challenges of follow-up studies focusing on the kind of changes that teachers would make in the textbooks they use in class if given the opportunity to do so; on how these changes might impact the teaching and learning of mathematics and how might conventional connections between teachers and other professionals be transformed on a large-scale basis to enable more equal positions and authority for teachers, and increase teacher agency. Likewise, following their detailed account of the collaborative university project run in Ontario since 2011, Martinovic and Horn-Olivito remind us of the challenges that Ontario educators still face in view of the recent education reforms that call for accelerated professional learning such as staffing schools with teachers-researchers, organizing schools as centers of inquiry, and promoting an inquiry-based leadership. I would add to the above future lines of investigation the need to better understand how mentors' actions and moves in the discourse eventually operate in each setting to influence the kind of learning environment that is accessed while learning in community. As Eteläpelto et al. (2005) contend, tutors and classroom teachers still need to understand how different kinds of participation connect to different kinds of learning experiences, and how aspects of participation such as power relations, cohesion, and emotional safety affect participants' positioning in a learning community. This is, indeed, a challenge called for in continuing studies in both settings. For example, in the context of the Ontario project guided by a strong institutional discourse with a defined hierarchy of roles, it seems imperative to further examine how mathematics learning teams were influenced by the mediating roles that supported the structures provided for to promote collaborative learning at the level of content, pedagogy, and leadership knowledge of administrators. It is also important to critically examine the evolving power relations and participants' positionings that developed throughout the project. This would entail looking deeper into the kind of talk promoted within the institutional constraints and affordances: *How do professionals talk to each other? What do they talk about? What kind of questions are being asked?* Examining these questions can shed light on how relationships in the discourse were determined by how participants positioned themselves in relation to others in terms of their perceptions regarding attitudes, roles, responsibilities, duties, and division of authority (Bullough & Draper, 2004).

4 Final Thoughts

My point here is: Teacher community cannot be the only lever for change, the expertise of the facilitator, the way in which participants collaborate to identify alignments and misalignments between content, form and message, as well as how people talk to each other and the power relations that develop in professional discourse in communities of learning, *do matter*. True, it is not yet clear how to predict what *really* produces the construction of knowledge in a community (Bereiter, 2002). Thus, studies point to a need to further look into the process by which participants construct professional knowledge during discourse, both individually and as a group (Lewis & Ketter, 2004). This would imply, amongst other things, establishing criteria for examining the *quality of learning interactions* that develop in different learning communities of practice. I call these two groundbreaking projects to further ponder on this aspect.

Finally, turning to a broader, global perspective on professional learning in an era of change, experienced professionals need to acquire professional skills and competencies for providing the right kind of mediation to support and guide processes of unlearning and relearning in community, to create meaningful reconstructions and revised understandings of 'taken for granted' realities. For future and novice professionals, it requires the development of professional careers that integrate the above new contents and processes of mediation—with a focus on the design and systematic investigation of innovative methodologies for the mediation of professional learning. Endorsing such an orientation towards training and educating the 'new professional' underscores the praxical character of professional learning at the intersection between theoretical knowledge at the academic setting, and case and practical knowledge at the workplace; reasoning, ethics, cultural awareness and responsiveness, thinking and acting (Orland-Barak & Maskit, 2017).

References

Bereiter, C. (2002). *Education and mind in the knowledge society*. Mahwah, NJ: Lawrence Erlbaum.

Bullough, R. V., & Draper, R. J. (2004). Making sense of a failed triad: Mentors, university supervisors and positioning theory. *Journal of Teacher Education, 55*, 407–420.

Clark, C. M. (2001). *Talking shop*. New York, NY: Teachers College Press, Columbia University.

Daloz, L. A. (1999). *Mentor: Guiding the journey of adult learners*. San Francisco, CA: Jossey-Bass.

Edmondson, A. C. (2003). Speaking up in the operating room: How team leaders promote learning in interdisciplinary action teams. *Journal of Management Studies, 40*, 1419–1452.

Edwards, A., Gilroy, P., & Hartley, D. (2002). *Rethinking teacher education: Collaborative responses to uncertainty*. London, UK: Routledge Falmer Press.

Engeström, Y., Engeström, R., & Suntio, A. (2002). Can a school community learn to master its own future? An activity theoretical study of expansive learning among middle school teachers. In G. Wells & G. Claxton (Eds.), *Learning for life in the 21st century* (pp. 211–224). Oxford, UK: Blackwell.

Eteläpelto, A., Littleton, K., Lahti, J., & Wirtanen, S. (2005). Students' accounts of their participation in an intensive long-term learning community. *International Journal of Educational Research, 43*(3), 183–207.

Feiman-Nemser, S., & Carver, C. L. (2012). Creating conditions for serious mentoring: Implications for induction policy. *Yearbook of the National Society for the Study of Education, 111*(2), 342–364.

Gawande, A. (2002). *Complications: A surgeon's notes on an imperfect science*. New York, NY: Metropolitan Books.

Gore, J. M., Griffiths, T., & Ladwig, J. G. (2004). Towards better teaching: Productive pedagogy as a framework for teacher education. *Teaching and Teacher Education, 20*(4), 375–387.

Lewis, C., & Ketter, J. (2004). Learning as social interaction: Interdiscursivity in a teacher and researcher study group. In R. Rogers (Ed.), *An introduction to critical discourse analysis in education* (pp. 117–146). Mahwah, NJ: Erlbaum.

Orland-Barak, L. (2007). Teachers learning communities: A socio-cultural perspective. In M. Zellermayer, E. Munthe, M. Gorodesky, F. Rust O'Connell, & L. Orland-Barak (Eds.), *Teachers learning in communities: International perspectives* (pp. 139–145). Rotterdam, The Rotterdam/Taipei, Taiwan: Sense Publications.

Orland-Barak, L. (2014). Mediation in mentoring: A synthesis of studies in teaching and teacher education. *Teaching and Teacher Education, 44*, 180–188.

Orland-Barak, L., & Maskit, D. (2017). *Methodologies of mediation in professional learning*. New York, NY: Springer.

Smith, J. K., Smith, L. F., & DeLisi, R. (2001). *Natural classroom assessment: Designing seamless instruction & assessment*. Thousand Oaks, CA: Corwin Press.

Tillema, H., & Orland-Barak, L. (2006). Constructing knowledge in professional conversations: The role of beliefs on knowledge and knowing. *Learning and Instruction, 16*(6), 592–608.

Timperley, H. (2001). Mentoring conversations designed to promote student teacher learning. *Asia-Pacific Journal of Teacher Education, 29*(2), 111–123.

Wang, J., & Odell, S. J. (2002). Mentored learning to teach according to standards-based reform: A critical review. *Review of Educational Research, 72*, 481–546.

Wilkins, R. (2011). *School research engagement: Whose agenda? Mapping the landscape for school leaders. International congress for school effectiveness and improvement, Limassol*. Retrieved from http://www.icsei.net/icsei2011/Full%20Papers/0044.pdf

Lily Orland-Barak is Professor of Education, former Dean of the Faculty of Education and present Dean of the Graduate Studies Authority of the University of Haifa. Her research focuses on the three complementary agendas in the field of Teacher Education and Professional Learning: Mentoring and mentored learning, teacher learning and curriculum development. She has endeavored to conceptualize mentoring as a manifestation of the acquisition of professional expertise, as it relates to contextual and discursive aspects of professional practice. She has published numerous articles on these topics including her book 'Learning to Mentor-as-Praxis: Foundations for a curriculum in Teacher Education' (2010) published by Springer and a recently published book on 'Methodologies for the Mediation of Professional Learning' published by Springer (2018). She serves on numerous national and international academic committees and editorial boards.

Part II

New Perspectives in Teaching Science and Mathematics: Israeli and Canadian Perspectives

Professional Learning Communities of Science Teachers: Theoretical and Practical Perspectives

Bat-Sheva Eylon, Zahava Scherz, and Esther Bagno

Preface

This section presents the flow and the general structure of the chapter and is followed by four parts.

The first part describes theoretical and practical perspectives on the continuous professional development of teachers, in general, and in Professional Learning Communities (PLCs), in particular. Three perspectives are discussed: (1) 'Research-Practice Partnerships (RPPs)' in which academic teams collaboratively carry out professional development programs with practitioners (teachers, teacher-leaders, school science coordinators, and science education administrators); (2) the 'scholarship of teaching' and the 'practitioner research' perspective; these deal with processes in which teachers systematically collect evidence on their own practice, explore relationships between these practices and their students' learning, share the evidence with peers and develop conceptual frameworks for understanding practice (Cochran-Smith & Lytle, 2009; Shulman, 2011); (3) the 'boundary crossing' perspective (Penuel, Allen, Coburn, & Farrell, 2015), which refers to ways people from different backgrounds learn to work productively with each other. This part also provides implications for designing science-based programs for PLCs.

The second and third parts describe exemplary case studies and models of two PLCs' programs: one for STEM teachers in middle school (grades 7–9) and the other for high-school physics teachers (grades 9–12). Both programs involve an academic team working together in a national PLC of teacher-leaders who enact regional PLCs and school-based PLCs of teachers around Israel. Key findings concerning processes and outcomes are discussed.

Bat-Sheva Eylon, Zahava Scherz and Esther Bagno have equally contributed to this chapter.

B.-S. Eylon (✉) · Z. Scherz · E. Bagno
Department of Science Teaching, The Weizmann Institute of Science, Rehovot, Israel
e-mail: bat-sheva.eylon@weizmann.ac.il; zahava.scherz@weizmann.ac.il;
esther.bagno@weizmann.ac.il

Y. Ben-David Kolikant et al. (eds.), *STEM Teachers and Teaching in the Digital Era*, https://doi.org/10.1007/978-3-030-29396-3_5

The fourth part – concludes the chapter by connecting research findings with theoretical and practical perspectives aiming to advance a design science for education (Collins, 1992). This part also discusses the models of the PLCs and principles for their design and implementation, and offers implications for future professional development of teachers.

1 Theoretical and Practical Perspectives[1]

1.1 Rationale

The need for ongoing learning by professionals, beyond their initial training and practice, has been recognized in many fields (e.g., medicine, law), and has led to the formation of a variety of continuing professional development programs (Hutchings & Shulman, 1999). In Israel, the importance of setting up such programs for educators has been one of the central recommendations of the 'Tomorrow 98 report'. This led to the design and enactment of a variety of programs in Israeli STEM education (Strauss, 2017), starting in the early 1990s. In the last several years, many professional development programs in Israel have been enacted as Professional Learning Communities (PLCs). Some of these PLCs target professionals from specific disciplines. These PLCs place a strong emphasis on the disciplines' content and capabilities.

The design and implementation of continuing professional development programs involves many stakeholders from the educational field (e.g., teacher-leaders, teachers, schools, districts, and local authorities), the Ministry of Education, and often professional foundations. Research-Practice Partnerships (RPPs) involving collaborations between academia and the field of education can play an important role in this endeavor (Bauer & Fischer, 2007). A review of RPPs in education by Coburn and Penuel (2016) highlights the important contributions of these collaborations (Bauer & Fischer, 2007), such as addressing persistent problems of practice, increasing the use of research in the practitioners' decision making, and improving educational outcomes. One additional contribution is practitioners' increased awareness of innovations in theory and practice and researchers' awareness of "... the realities and concerns of those working in classrooms" and thus, increasing the ecological validity of the outcomes (McKenney & Pareja Roblin, 2018).

However, Coburn and Penuel (2016) claim that:

> … many questions about running productive RPPs are unresolved…. We need targeted studies of specific strategies that partnerships use. Existing research tends to focus on the challenges, providing little insight into how tools, strategies, and routines used by participants address these challenges. (p. 52).

---

[1] Written by Bat-Sheva Eylon.

The two models of professional development programs described in this chapter involve ongoing RPPs between teams at the Weizmann Institute and practitioners (e.g., with teacher-leaders in the PLCs). The studies that accompanied the models dealt with strategies that addressed challenges in running the programs thus responding to the above mentioned need as discussed in the conclusion part.

In the next section we lay out several important considerations in designing professional development programs for teachers. These considerations, together with the theoretical perspectives, described in the sections that follow, lead to the implications for the design and implementation of PLCs that are described in the end of this part.

1.2 Professional Development Programs and Teachers' Learning

In designing professional development programs aimed at teachers' learning, a basic consideration is that teachers are adult learners (Knowles, 1990; Pinto & Cooper, 2016). Research shows that teachers' learning requires carefully crafted learning processes over time, and that in order to have an impact on teachers' views and practices, it is useful to continuously situate their learning in practice (Eylon & Bagno, 1997; Timperley, Wilson, Barrar, & Fung, 2008; Whitcomb, Borko, & Liston, 2009). Hence, it is recommended to design for teachers long-term continuing professional development programs Central activities comprising these programs involve an 'evidence-based approach' in which teachers have opportunities to discuss and reflect collaboratively with peers on their practice and their students' learning using authentic materials from classes (e.g., students' works and videos of lessons) (Borko, Koellner, Jacobs, & Seago, 2011; Darling-Hammond & Richardson, 2009; Little, 2012; van Driel, Meirink, van Veen, & Zwart, 2012). Our experience in running such programs revealed that teachers often lack some important skills that are needed in working with such an approach (e.g., the ability to differentiate observations from interpretations), and therefore, it is important to provide them with some guidance (Eylon & Bagno, 2006; Eylon, Berger, & Bagno, 2008; Harrison, Hofstein, Eylon, & Simon, 2008; Scherz, Eylon, & Bialer, 2008).

However, when teachers examine their students' learning systematically, their engagement, willingness to "listen" to their students, and to make important changes in practice evolves (Arcavi & Isoda, 2007; Feiman-Nemser, 2001). They also develop as 'reflective practitioners' (Borko, Jacobs, & Koellner, 2010). Development of a reflective stance, accompanied by an evidence-based approach, is therefore central in building 'teachers' capacity' and capabilities for future life-long learning (Scherz, Bialer, & Eylon, 2011). The theoretical perspective of 'practitioner research' is described in greater detail in the next section

We mentioned here only a partial list of characteristics that enhance teachers' learning. Additional important insights are described in the theoretical perspectives that follow.

1.3 Scholarship of Teaching and Practitioner Research

The literature on ‘scholarship of teaching’ (e.g., Hutchings & Shulman, 1999; Shulman, 2011; Trigwell, Martin, Benjamin, & Prosser, 2000) and on ‘practitioner research’ (Cochran-Smith & Lytle, 2001, 2009) provides insights into the nature of teaching as a profession and ways that scholarship develops within communities of teachers, teacher educators, and researchers.

The following desired characteristics of engagements in professional learning communities are highlighted by this literature:

1. Commitment to systematically exploring the participants’ own teaching, as reflected in students’ learning, or what Cochran-Smith and Lytle (2001) refer to as, “generating local knowledge of practice”.
2. Sharing this knowledge within a community of teachers and thus making it “community property” that can be “subject to peer review and evaluation, and accessible for exchange and use by members of one’s disciplinary community” (Shulman, 1997, 2011).
3. A community effort to “go meta” (Shulman, 1998, 2011) and develop conceptual frameworks for understanding practice (Cochran-Smith & Lytle, 2001). This process enables developing principles that cut across contexts, and to involve “building, interrogating, elaborating, and critiquing conceptual frameworks that link action and problem-posing to the immediate context as well as to larger social, cultural, and political issues” (Cochran-Smith & Lytle, 2001, 2009).

Kali, Eylon, McKenney, and Kidron (2018) describe several aspects that play an important role when an RPP community (e.g., researchers and teacher-leaders) collaboratively designs and enacts programs that promote the above-mentioned characteristics and that lead to sustainability: (1) Having members of the community participate in the design process, the enactment of activities, and in trying out emerging ideas at the community’s meetings and in the teachers’ classes. (2) Fostering a symmetric role between members of the RPP community regarding the design, enactment, and research responsibilities. This is essential for developing autonomy and ownership by the practitioners and for developing sustainable programs. Appropriate social, organizational, and digital infrastructures are important for facilitating the achievement of this goal (McKenney, 2016). (3) Inculcation of habits of mind involving trust, empathy, and flexibility. Such habits of mind are essential for developing the capacity to sustain change and to carry out work across contexts, and require norms of interaction and shared commitments (Donovan, Snow, & Daro, 2014). In productive educational collaborations, trust is developed by engagement that is deep, direct, and frequent (Penuel, Bell, Bevan, Buffington, & Falk, 2016). Empathy and flexibility are needed for exploring and attending to the needs, wishes, and concerns of stakeholders.

Since the RPPs involve people from different backgrounds who work together in designing and enacting the professional development programs, differences in views and norms often require mutual learning and ‘boundary crossing’.

1.4 Boundary Crossing

The ‘boundary crossing’ construct refers to ways people from two or more different backgrounds learn to productively work with each other. It acknowledges the fact that differences in views and norms may lead to gaps and thus, there is often a need to “cross boundaries” in order to realize and understand everyone’s views and attitudes, and to learn to cooperate. Mutual learning is an essential process that must take place. The boundaries that participants need to cross may be cognitive as well as socio-cultural (Penuel et al., 2015). Akkerman and Bakker (2011) defined four learning mechanisms (or boundary crossing processes) that take place in such situations: (1) learning to recognize others’ points of view (identification), (2) looking for ways to cooperate with others within the existing framework and constraints (coordination), (3) taking other perspectives into account in planning and acting (reflection), and (4) transforming one’s point of view (transformation). Although these processes may progress in different orders, reflection, and eventually transformation, usually stem from earlier identification and/or coordination processes (Akkerman & Bruining, 2016). In partnership models involving researchers collaborating with practitioners, changes may occur on both sides due to mutual learning. Central strategies that are important in transformative learning (Kali, 2016) include the building of a common language, opportunities for using ideas in a variety of contexts, explicating the rationale of actions carried out in professional development programs, forming connections with specific situations (meta-cognition), and combining top-down (e.g., conceptual frameworks) with bottom-up insights of practitioners from exploring their practice.

1.5 Professional Learning Communities (PLCs)

The ‘scholarship of teaching’ and ‘boundary crossing' perspectives emphasize the importance of approaching educators as professionals participating in continuing professional development programs, aiming at promoting ongoing learning and focusing on the teaching profession. Not every course for teachers, or other settings in which teachers work together has the potential to support ongoing learning and changes in teachers as professionals. However, teachers’ PLCs have that potential (Grossman, Wineburg, & Woolworth, 2001; Shulman, 1997). The models of PLCs described in parts 2 and 3 exemplify approaches that were taken to achieve this potential. The reported research on the processes and outcomes in these PLCs illustrate challenges that faced the research-practice partnership and mechanisms that fostered professional development of the participating teachers.

There is no consensus in the literature regarding the definition of PLCs. Considering some of the characteristics that are highlighted in many studies (Bolam et al., 2005; DuFour, 2004; Koellner, Jacobs, & Borko, 2011; Little, 2012; Vescio, Ross, & Adams, 2008) and our own experience in running research-based continuing professional development programs with science educators (see Sect. 1.2), led us to the following characterization: PLCs provide a framework for a group of educators to meet regularly and develop norms of trust and sharing. The educators actively investigate their teaching, collect evidence from their practice and their students' learning, reflect collaboratively on their practice, and learn from one another.

Presently there is a national initiative that promotes the enacting of regional and in-school PLCs in Israel carried out in different content areas (e.g. mathematics, English). In particular, there is a major effort to distinguish PLCs from other professional development programs. The following are the major characteristics of PLCs that have been identified and adapted by this initiative (see Table 1) and are tailored in the PLCs to the different content areas. The characteristics also refer to aspects that were derived from the experiences of various PLCs that were carried out in the last several years in Israel, in particular, from the two PLCs described in the next two parts of this chapter, which served as pioneers in conceiving, enacting, and researching PLCs on a national scale. The characteristics have also been negotiated with relevant stakeholders including policy-makers from the Ministry of Education, as well as school principals, regional authorities, and teams implementing PLCs. Views of practitioners such as teacher-leaders and teachers, as well as in-situ observations provided input to this process.

Table 1 The characteristics of PLCs[a]

Characteristics	Description
Relations of trust and norms of sharing	Relations of trust and mutual respect create a safe environment that enables teachers to learn and develop professionally. The PLC serves as a responsive and proficient "safety net" in the event of challenging experiences.
Regular meetings and mechanisms, structured processes	Optimal learning processes require well-maintained regularities: regular meetings with schedules and incidences, meeting times, inviting physical conditions, and more.
Focus on student learning, and the connections between teaching and learning	Pedagogical discourse in the PLCs should focus on student learning and its relationship to teaching.
Decision-making based on data collection and evaluation	To increase better learning and teaching – alternative assessment methods should be used (e.g., systematic analysis of student assignments, classroom observations, interviews) on when collecting, understanding, and interpreting of data.
Reflective dialogues, enquiry, and reflection	Effective professional learning involves collective reflection on practice, examining teaching methods, and continuous self-examination, including structured processes for "learning from successes and failures".

[a] Following DuFour (2004) and Benaya, Yakobson, and Zadik (2013)

2 Professional Learning Communities (PLCs) for Middle-School STEM Teachers: An Evolving Model[2]

2.1 Introduction and Background

Teaching Science and Technology in middle schools presents significant challenges as well as enormous opportunities. Science and technology are among the most important resources of modern society and for this reason a science and technology education for every child should be an important educational mission for the education system. According to the present regulations of the national curriculum in Israel, science is not compulsory after middle- school (grades 7–9) and therefore, middle- school may be the last opportunity for Israeli children to acquire a basic STEM education and to develop positive attitudes toward the STEM subjects. The methods and pedagogies used for STEM subjects that are taught at this stage, to a great extent, determine whether and how many students continue studying STEM in high school. Therefore, teachers need to develop continuously their disciplinary knowledge, their pedagogical content knowledge and their ability to integrate twenty-first century skills into their STEM teaching. In this study we advocate that PLCs are appropriate frameworks for developing and implementing such expertise (Borko et al., 2010; DuFour, 2004).

Our PLCs novel program has been operating under the auspices of the Weizmann Institute's Department of Science Teaching for the last four school-years, with funding from the Trump Foundation and with cooperation from Israel's Ministry of Education.

An exemplary story is presented that illustrates the development of our STEM PLCs and the unique character of the program as a whole. It concludes with an explanation of how the process resulted in creating a complex network model of knowledge transmission among STEM teachers' PLCs, and between these PLCs and middle-school students.

2.2 The STEM PLC Program

Toward the beginning of the 2015–2016 school year, the Weizmann Institute of Science's Department of Science Teaching launched a 4-year program for developing PLCs for middle-school STEM teachers. Inspired by the experience of already existing PLCs for the Physics teachers' (see Part 3), we tailored our PLC program according to the unique professional needs and diverse profiles of middle-school STEM teachers and students.

The initial model, which represents the structure of our STEM PLC program consisted of a leading team from the Weizmann Institute's Department of Science Teaching,

---

[2] Written by Zahava Scherz.

which sought to: (a) create and monitor a national PLC of leading STEM Teaching (teacher-leaders' PLC); (b) establish regional PLCs of STEM coordinators and teachers; (c) enhance school-based learning communities for STEM teachers' teams; (d) promote meaningful, high-quality, and challenging teaching in STEM classrooms; (e) provide students with meaningful learning, positive attitudes, and eventually, increase their motivation to continue studying STEM in high school (see Fig. 1).

The overall numbers of our STEM PLCs increased during the four years of implementing the PLC program (Table 2).

First Year In the program's first year (2015–2016), the national teacher-leaders' PLC consisted of 9 middle school STEM instructors and coordinators, and 10 members of the Department of Science Teaching (three faculty members who are directing the program, other department members, a psycho-pedagogical advisor, Ph.D, students, and postdoctoral fellows). All meetings (4 hours each – a total of 60 h) of the teacher-leaders' PLC had a fixed structure consisting of the following sessions:

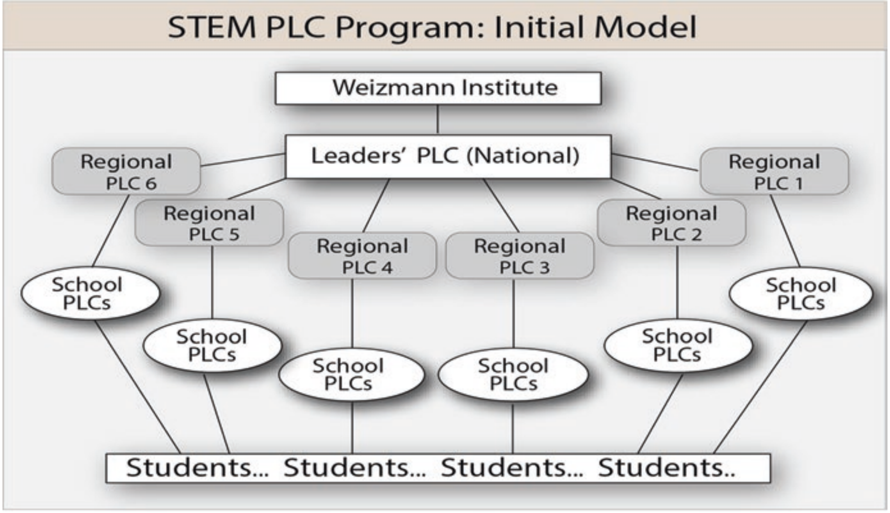


Fig. 1 The initial model of the STEM Program

Table 2 Teachers' learning communities for STEM middle schools

Years	Number of PLCs
2015–2016	1 national teacher-leaders' PLC
2016–2017	2 teacher-leaders' PLCs 5 regional PLCs
2017–2018	2 teacher-leaders' PLCs 12 regional PLCs
2018–2019	2 teacher-leaders' PLCs 17 regional PLCs

- **An opening session**, geared toward establishing a sense of connection;
- **A content-knowledge session**, relating to science content-knowledge and/or STEM education;
- **A PLC session**, pertaining to defining, developing, and implementing PLCs, e.g., sharing experiences, collaborative learning, leadership strategies, psycho-pedagogy; and
- **A closing session,** aimed at summing up and reflection.

All the above sessions were carried out in the context of STEM education issues and contents. Each meeting also included a pleasant mealtime and the participants were asked to fill out an on-line feedback questionnaire, which was subsequently analyzed and addressed. Members of the leaders' PLC also implemented PLC activities in their STEM classroom between meetings, as well as during meetings of their STEM school-based communities. Throughout the year, the PLC leaders compiled an evolving on-line folder of all the activities that took place in their PLC. A selection of those activities was available to share with other teacher-leaders.

Interviews and concluding discussions toward the end of the first year reflected a strong sense that the initial group members had become a PLC of leaders. The results indicated that the group performed as a PLC regarding most of the characteristics previously mentioned (see Table 1). Improvement was still needed, however, in terms of "work in light of the growing data and evaluations". While preparing for the second year of the program, cooperation was established with the Ministry of Education's professional supervisory division, and together, we decided to continue developing teacher-leaders' PLCs and to start five new regional PLCs for the 2016–2017 school year.

Second Year In the program's second year (2016–2017), the original teacher-leaders' PLC continued to meet on a regular basis, and all of its members began the process of setting up PLCs in different regions of the country. In addition, a second national teacher-leaders' PLC with 19 members was established, as were five regional PLCs – each under the leadership of two members of the initial teacher-leaders' PLC.

Third Year Towards the program's third year (2017–2018), in the spirit of our experience and following the model described above, a "regulatory program" was created under the auspices of the Ministry of Education in order to formally promote disciplinary PLCs and to provide resources and logistical support. This change enabled our program to expand – the two teacher-leaders' PLCs continued to operate, and new teacher-leaders joined their ranks. The five **regional** communities that began operating in 2016–2017 continued meeting thereafter, and six new regional PLCs were established in different parts of the country, under the supervision of the Weizmann Institute.

Each year, the teacher-leaders and the regional PLCs started a vibrant professional WhatsApp group, in which norms were established to deal solely with professional matters (regarding the sharing of pictures, activities, tips, and insights from regional communities, and discussions took place regarding issues in science and the teaching of science). In this way, and without any advance planning, the activity and learning that took place in the communities expanded beyond the official PLC meetings.

2.3 The Model: Evolving from Hierarchical Model to a Network Model

The program included components of formal and informal evaluation, as well as feedback forms. The research team conducted interviews and observed classrooms, which were combined into a variety of "PLC stories", taken from various STEM-related topics. Regular follow-ups and analysis of these stories helped us to better understand how a PLC develops.

2.3.1 The Ice-Water Glass Story

"The ice-water glass" below is one exemplary story, taken from material sciences, which provides a flavor of our STEM PLC meetings. It also sheds light on the learning processes inside a PLC, between PLCs, and how they relate to students' learning.

"The ice-water glass" activity is a diagnostic activity that was carried out in the teacher-leaders' PLC. It involved observing a glass filled with ice and water; the participants were asked to draw a microscopic structure of all the materials inside the glass, to share their drawings with others, and to explain them. The use of visual means forced the students to reveal their level of understanding (or misconceptions/lack of knowledge) of the structure of materials. Observing the drawings of various students initiated a pedagogical content-related discourse and a class discussion. The activity was also demonstrated on the STEM teachers' website and included a video and instructional materials.

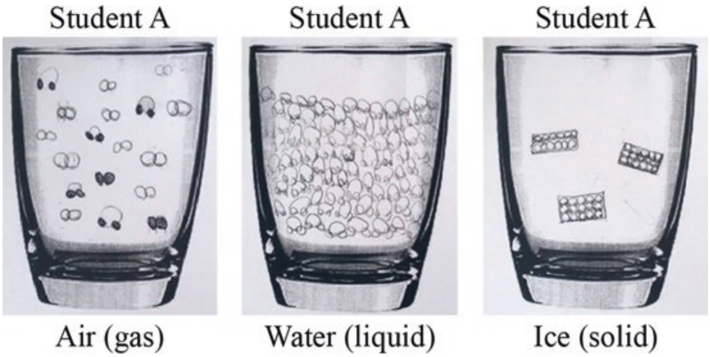


Fig. 2 Student A's drawings: the microscopic structure of substances inside the ice-water glass

Next, the teacher-leaders' PLC members embedded the activity in the regional PLCs; from there it was introduced to the school-based communities and to their STEM classes. Relevant drawings, which were collected from the participating PLCs (teachers as well as students), were shared, analyzed, and discussed at PLC meetings. In one regional PLC, "the ice-water glass" activity was demonstrated, and recommended for "assessment for learning". The teacher, N, who belongs to that PLC, implemented the activity in her 8th grade STEM class. Student A, who was shy and secluded, seemed to be unusually engaged in the activity, and teacher N asked him to share his drawings with the class. The students and the teacher were astounded when they realized how accurate his drawings were (see Fig. 2). He correctly identified all three materials in the glass: water, ice, and air, and correctly drew their detailed molecular structure. Unlike student A, other students did not mention the presence of air, and many drew incorrect microscopic drawings.

The use of visual means encouraged Student A "to come out of his shell" and to show his drawings to the whole class. As a result, his personal image, in the eyes of those around him, was totally altered, which improved his self-image and social behavior.

Teacher N reported Student A's story to the regional PLC, where it was discussed, and from there it was referred back to the teacher-leaders' PLC program at the Weizmann Institute of Science.

Teacher N, who is also a STEM coordinator at her school, shared the ice-water activity with her school-based PLC members, who, in turn, used the activity in their STEM classes. Teacher N also reported the story in the school newsletter. Figure 3 traces this Ice-Water story as a compound path of "knowledge transmission" that occurred between the Weizmann Institute, different PLCs, and students.

2.3.2 The Evolving Network Model

Additional stories were written, analyzed, and presented as various graphic paths of "knowledge transmission" and were drawn as a combined illustration as shown in Fig. 4.

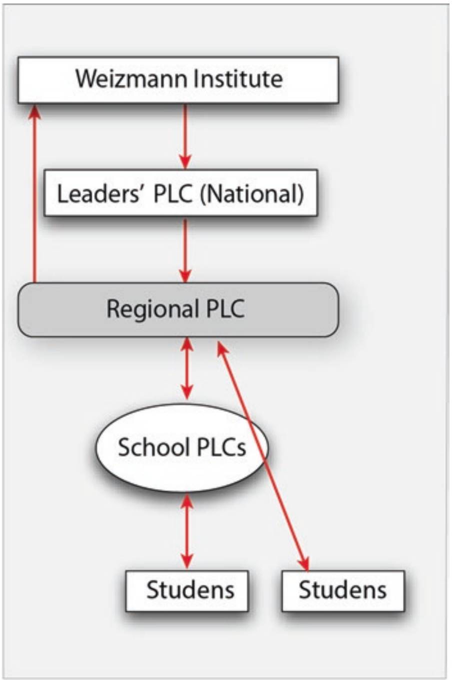


Fig. 3 Graphic representation of the ice-water glass story

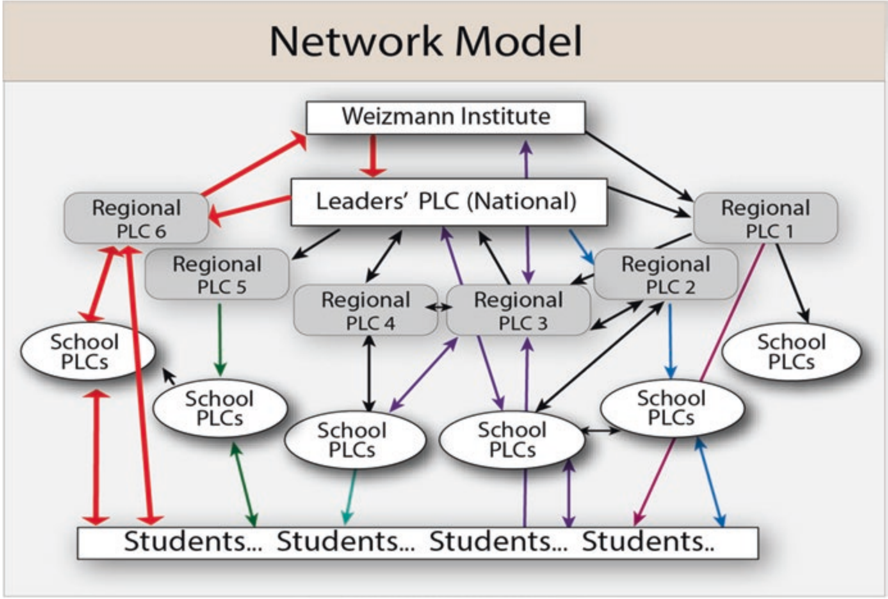


Fig. 4 The Network Model: knowledge transmission paths among STEM PLCs

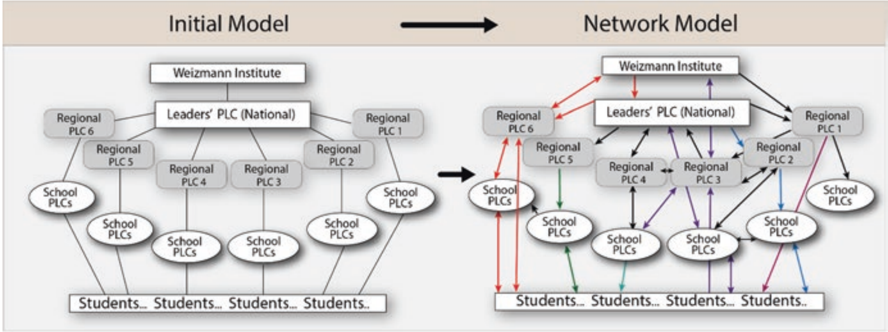


Fig. 5 STEM PLC's Knowledge-Transmission Model: from Initial (Hierarchical) to a Network Model

The "ice-water glass" story (Fig. 3) is also represented on the left hand side of Fig. 4 (bold red arrows), adjacent to other knowledge-transmission paths. The empirical research (observations,

interviews, and more) indicates that the “initial (hierarchical) model” was transformed into a “network model”, shown in Fig. 5.

It is clear that knowledge transmission occurs among PLCs in many directions: from the teacher-leaders’ PLC to the regional PLCs and vice-versa, and from there to other school-based PLCs, and to other educational initiatives outside our PLCs program.

2.4 *Outcomes*

Our PLC program for middle-school STEM teachers consists of a complex, non-linear professional development process; it generated influential results that were sometimes unexpected**.** We will conclude by referring to some of them.

2.4.1 A Variety of PLC Profiles

Our PLC meetings are geared to develop the characteristics that were discussed in Part 1 (Table 1). For example, participants are expected to share their unique and special teaching experiences with other PLC members. Our findings show that PLC members who do not share their experiences and/or problems with other PLC members eventually drop out of the group. As a result, each PLC develops a distinctive collective professional profile, which combines professional characteristics such as STEM proficiency, a sense of mission, a desire for excellence, passion, commitment, and a desire to have an impact.

2.4.2 The Network Model

The network model that emerged throughout the implementation of our PLC program brought about various knowledge transmission processes, both within a single PLC and between PLCs. The network model demonstrates relationships between individuals who share the same views within a specific community, as well as direct and indirect relationships between regional and leading-teachers' PLCs. These relationships motivate and influence those that participate in the PLCs. Our findings indicate that important, relevant knowledge is conveyed within the PLC network, which improves and becomes more accurate over time, whereas knowledge that is inadequate (for teachers or students) diminishes and eventually disappears.

2.4.3 Impact on Teachers and Students

Belonging to a PLC enriches teachers' up-to-date STEM-based knowledge, as well as their pedagogical content knowledge. It also expands and deepens the members' general pedagogical knowledge, strengthens and develops their leadership skills as well as encourages innovation and creativity (Scherz, Eylon, & Yarden, 2018).

The teachers use diverse and creative methods for implementing what they acquire in the PLCs and consequently employ diverse teaching methods that encourage meaningful learning. Through the PLC mechanism, activities that are developed within PLCs are offered to a variety of students with diverse interests and needs. This paves the way to improving students' performance and attitudes, and may encourage them to choose a STEM subject in their future studies.

We believe that the PLCs constitute an appropriate, up-to-date, and innovative framework for the ongoing professional development of teachers in the twenty-first century – one that can either replace or operate alongside the traditional professional training programs.

3 The PLCs of Physics Teachers in Israel[3]

3.1 Introduction and Background

In a process that began more than two decades ago and has continued until the beginning of this current decade, the number of high-school students who chose physics as their major declined constantly. Moreover, many students who started learning physics have dropped out and changed their major.

In an attempt to scrutinize this situation, we turned to the two main players – the physics students and teachers – to reveal their attitudes, thoughts, and views about

---

[3] Written by Esther Bagno.

learning and teaching physics. In an online survey, administered to 600 students in 2011, the findings showed that most of the students thought that learning physics is difficult and requires investing a lot of time and effort, that physics lessons are not very interesting, and that students with difficulties receive no support. Another disturbing issue was the relatively small number of girls who chose physics as their major. However, when the focus was turned to the physics teachers, it became clear that their views are not so different from those of their students: many teachers thought that learning physics is really difficult, and thus, only the most talented students are capable of and should learn physics.

With these findings in mind and with insights originating from research claiming that teachers are the central factors in students' learning (Harden & Crosby, 2000), it became clear that teachers should be aware of the inherent difficulties in many of the physics concepts and principles, and they should know how students learn and how to address their individual needs. In addition, they have to know how to motivate students, and how to attend to their diverse needs in terms of learning styles, interests, and specific problems. In other words, teachers have to orient their teaching towards a more "learner-centered" approach.

In planning and designing ways to support teachers' learning as "adult learners" (Gregson & Sturko, 2007), several significant aspects have to be taken into consideration, such as teachers' working conditions as well as their needs and their motivation to undergo a change process. High-school physics teachers in Israel are overloaded with a very demanding physics curriculum and are in a race against time in preparing their students for the final matriculation examinations, which greatly influence students' final grades. Moreover, in most of the schools the physics teacher is the only one teaching the subject, especially in grades 11 and 12; at best there may be just one other such teacher. Consequently, there is usually no teamwork, and no one to consult with and share their experiences, thoughts, and dilemmas. In addition, they generally do want to deepen their knowledge of physics, make their teaching more diversified and interesting, and integrate "cool" ideas into their physics lessons.

The PLC program for physics teachers in Israel began in 2012 in order to address all of these issues. The platform of PLCs enables creating an effective and useful discourse among the participating teachers, through which they can share their ideas, insights, and experiences, give and get support, and reflect together on their practice. During the community meetings, the teachers may undergo substantial learning processes towards achieving a more learner-centered approach to teaching physics (Levy et al., this book).

3.2 The Physics PLC Program

The program has operated since 2012 by using a "Fan Model." Currently, 25 teacher-leaders participate in a PLC led by a team from the Department of Science Teaching at the Weizmann Institute of Science in Israel. The team simultaneously leads 12 regional PLCs of high-school physics teachers all over the country (2–3

Fig. 6 The "Fan Model" used in the physics teachers' PLC program

teacher-leaders per community), with about 240 high-school physics teachers (about 20% of all high-school physics teachers in Israel), teaching approximately 15,000 students. Each PLC, including both the teacher-leaders' PLC and regional PLCs, meets during the school year face-to-face twice a month for 4 hours, totaling 60 hours per year (Fig. 6).

Before and during each PLC meeting, refreshments are served, which are the responsibility of the teachers themselves. Teachers use this delicious gathering time to consult each other and to clarify physics ideas that they are not very sure about.

Each PLC meeting consists of two parts: the first part is usually dedicated to the teachers' daily needs. Here, teachers share diverse and interesting ideas, such as the use of toys, thought-provoking experiments, and surprising simulations. The second part of each meeting deals with in-depth learning processes aimed at more "learner-centered" physics teaching approach elaborated in the following section.

3.3 *The Model: Teachers' Learning Towards Learner-Centered Approach*

According to Ausubel (1968) "…the most single factor influencing learning is what the learner already knows. Ascertain this and teach him [sic] accordingly". This "learner-centered" approach to learning is substantiated and elaborated more in a meta-analysis of many learning experiences, which can be summarized by three principles: new knowledge has to be connected to the learner's prior knowledge, it has to be organized in conceptual frameworks, and the learner has to be responsible for her/his learning (Donovan & Bransford, 1999). A knowledge-integration perspective on learning (Linn & Eylon, 2006, 2011) is useful for designing such learning experiences. It is based on cognitive and socio-cultural theories of learning and offers both theoretical lenses and practical guidance. According to the knowledge-integration perspective, learners build knowledge by undergoing four learning processes: (1) Eliciting prior knowledge: learners become aware of their pre-existing knowledge; (2) Adding new ideas: learners are introduced to ideas that are new to them. These ideas may come from various sources such as a teacher, a textbook, a peer, or the Internet; (3) Developing criteria to evaluate ideas: questions and tests are used by the learners to evaluate whether they consider the ideas acceptable. Examples of such criteria are, whether the origin of the new ideas is reliable (i.e., based on scientific principles) and whether there are contradictions within the ideas acquired, or between them, and the ideas that are already known to the learner; (4) Sorting out and reflecting: the learners reflect on and differentiate between their pre-existing ideas and the newly acquired ones based on specific criteria. The four processes do not necessarily appear one after another, and are not always in the described order. Teachers' learning towards a learner-centered approach is carried out through carefully crafted learning sequences examined in light of the question of whether they call for the existence of the four knowledge integration learning processes. That is, whether each teacher is given the opportunity to elicit, add, and enrich the previous knowledge, discuss it with friends, examine it in light of agreed criteria, and finally compare the initial knowledge with the new knowledge. During the seven years of the PLC program several knowledge-integration based learning sequences were used with physics teachers. An example follows.

3.4 *An Example of a Learning Sequence Towards Learner-Centered Approach*

The goal of this learning sequence was to convince teachers that even "simple and understandable" concepts may be difficult for some students and that repeated explanations do not always manage to address these difficulties. Therefore, it is important to address students' difficulties through specific learner-centered teaching strategies.

At the center of this learning sequence was a multiple-choice diagnostic question taken from the professional literature. The question focuses on students' understanding of a seemingly "innocent" physics concept. The distractors of the question are built around common students' mistakes in understanding this concept. One of the distractors is the correct answer. The student is asked to mark the correct answer and to explain the choice.

"Wearing the hats" of students by answering the diagnostic question was the first stage of the learning sequence. It took place at the PLC meeting. Its goal was to enable teachers to elicit their initial knowledge about students common learning difficulties that are often not affected by traditional teaching. Teachers answered the question individually, discussed the answers in groups with colleagues, and presented a summary of the group discussion in the plenum. The conclusion usually reached by teachers at the end of this meeting was that the concept is simple enough and after "good" instruction, it will be understood by most students. A similar approach is reported by Milner-Bolotin, Fisher, and McDonald (2013).

Implementation in classes was the second stage of the learning sequence. Its goal was to add to the teachers' initial knowledge some information derived from authentic data on students' learning. This new information would serve as a background for discussions between the teachers at the following PLC meeting. Each teacher administered the diagnostic question in their classroom and inserted students' responses to the diagnostic question in a collaborative Google form. In addition, teachers collected several activity sheets, including interesting students' explanations to the choice of their answers.

Collaborative analysis of students' answers was the next stage of the learning sequence, again it took place at the PLC meeting. Its goal was to stimulate "evidence-based" discussions between teachers about possible reasons for students' difficulties, rather than having teachers express their individual views and impressions.

Teachers in small groups analyzed several student activity pages they brought from their classes and discussed possible reasons for their students' mistakes. These reasons were discussed in the plenum and were grouped as a list of criteria agreed upon by all the teachers. At the same time, the quantitative data (from the Google-form) on the responses of numerous students from different classes added up to numbers that were very surprising to the teachers. At the end of this meeting, the teachers were more willing to share with fellow teachers their experiences, not only the successful ones.

Collaborative reflection was the "Aha moment" stage of the learning sequence and a large part of the meeting was devoted to it. The goal of this stage was to encourage reflective processes that will modify or expand the teachers' prior knowledge of the students' conceptual difficulties and evoke the teachers' desire to think about new ways to deal with these difficulties. The teachers, in turn, retold the story of their students' experience with the diagnostic question, sharing both disappointments and insights. The teachers began to ask themselves reflective questions such as, "How did I not know this?"; "Even the best students were wrong?"; "I thought my explanations were helpful to everyone." Following this reflective learning process, many teachers asked the question, "So, what do we do now?" They were eager to begin thinking about various ways to help struggling students, were willing to familiarize themselves with teaching strategies aimed at addressing the difficulties encountered, and sought diagnostic questions and advice in other subjects as well.

Meta-cognitive view of the whole learning sequence was the final stage of each learning sequence. We discussed with teachers how the learning sequence they had experienced is related to the KI Perspective on learning. We discussed the merits of each stage and what could have been done differently. Discussions of this kind distil the essence of the learner-centered approach to teaching and even stimulate a discussion of effective ways to engage students in learning.

3.5 Outcomes

We examined the outcomes of the program through the following three “big” questions: Where are we in our journey towards:

- Responding to teachers’ needs?
- Promoting a learner-centered approach in physics learning and teaching?
- Fostering students' learning?

In order to address these questions, we examined a large amount of various types of data collected during the seven years of the program (e.g. video-tapes of teachers’ meetings, interviews, portfolios, and several case studies; students’ materials from classes, and anonymous questionnaires for students). Our data analysis is primarily based on qualitative methods; however, we also used descriptive statistics. Next, we present very briefly some representative answers to the above questions.

3.5.1 Responding to Teachers’ Needs

Our findings indicate that the program responded to a large variety of teachers’ needs.

They were very grateful for having new opportunities to consult, share their practice, and learn together: “I feel that I’m not alone anymore” More than 90% of the teachers reported that they integrate into their physics lessons, on a regular basis, new learning aids (e.g., toys, film-strips, demonstrations, simulations, pictures). Teachers voiced enthusiasm and “passion” regarding the program (Shulman, 1997).

“Even after a very hectic day in school, I’m so glad to come to the community meeting and meet these experienced physics teachers. We learn together and it is fun”. They reported that they are happy to realize that their “voice matters,” that they are “updated in what is new in physics,” and that their “self-confidence is increased.” For novice teachers, “socializing into the profession and the shaping of a new professional identity by interacting with colleagues” was both important and rewarding.

3.5.2 Promoting a Learner-Centered Approach in Physics Learning and Teaching

Teachers underwent ongoing complex processes during their professional development towards achieving learner-centered knowledge, perceptions, and practices. They acquired a wider perspective on physics teaching, a better awareness of students' difficulties, and addressed them in teaching (for more details, see the chapter in this book written by Levy et al.). According to our findings, all of the leading-teachers and most of the regional PLC teachers regularly used part of the new learner-centered teaching strategies offered in the program in their own classrooms, often for several years after they had learned them.

3.5.3 Fostering Students' Learning

More than 70% of the students reported that their teachers use learner-centered practices (e.g., diagnostic questions, 'wait time', and group work). More than 60% of the students reported that there is a supportive atmosphere in their class, e.g., "I feel comfortable to ask questions, my success matters to my teacher".

Presently, after seven years of running the program many of the teachers continue to participate, and new teachers enroll. Also, most of the teacher-leaders continue to participate and new teacher-leaders are joining. We believe that attending to teachers' daily needs and promoting learner-centered teaching approaches are the key to the outcomes and sustainability of the program.

4 Conclusion

The chapter describes theoretical and practical perspectives on the continuous professional development of teachers in Professional Learning Communities (PLCs), and two PLCs that were carried out by academic teams and practitioners: teacher-leaders and teachers. Exemplary case studies, carried out in the PLCs, demonstrate main characteristics of these PLCs. The PLCs are disciplinary and situated in science related contents and are geared to promote teachers' pedagogical knowledge and pedagogical content knowledge. In particular, they intend to improve teachers' practice towards a learner-centered instructional approach, to develop their reflective stances towards their practice, and to elevate students' performance and motivation to study science.

Innovative resources and activities were carefully constructed to enable teachers to gain insights about their students' learning. The teachers experienced activities, first as learners, then tried them in their classes, and finally reflected collaboratively with peers on their practice and their students' learning using authentic evidences from classes. For example, to examine students' conceptual understanding in middle-school STEM classes, students were asked to represent visually the microscopic composition of materials inside an open glass containing ice and liquid water; in the high-school physics PLCs teachers asked their students to answer diagnostic questions and to explain their answers, and discussed their responses collaboratively.

The PLCs introduced techno-pedagogical means to scaffold the teachers' professional development, for example an ongoing compilation and sharing of an online folder of all the activities and resources in the middle-school PLCs, and an automatic collection of students' work on a national scale in the physics PLCs. These means enhanced teachers' ability to change and customize their work both in classes and in the PLCs. Frameworks such "the Characteristics of PLCs" listed in Table 1, in the middle-school program, and the "Knowledge Integration Processes" in the physics program, encouraged the building of a common language and the ability of teachers' to refine their conceptualization and meta-cognitive stances (Kali, 2016),

The PLCs were accompanied by research aimed to study processes and outcomes using tools such as questionnaires, observations, and interviews. Results indicated changes in teachers' attentiveness to their students' learning and their engagement in enhancing and developing their practice. Examining findings regarding practical perspectives such as 'Teachers as adult learners' indicated that the programs indeed responded to teachers' concerns and needs, such as making their teaching relevant and interesting to the students, and the need to meet and share practical experiences and professional concerns with each other.

Examining processes in the PLCs through the theoretical perspective of the 'scholarship of teaching and practitioner research' indicated that teachers became more committed to systematically explore their own teaching and its reflection in their students' performance, and to share this knowledge with their community peers. They also developed collaboratively conceptual tools for better understanding their practice, which gradually became a "*community property*". The 'boundary crossing' perspective highlights processes of mutual learning between the researchers and the teachers in the PLCs which is important for building teachers' autonomy and ownership, and therefore encourages sustainability (McKenney, 2016).

The findings illustrated in the case studies indicate that the hierarchical, topdown approach that characterized the initial management of the PLCs was gradually transformed into interactive and collaborative learning and sharing of responsibilities between the PLCs members. This led to a "change in roles" that enabled "knowledge transmission" between the academic teams, the practitioners and the students. These interactions and their on-going effect is represented as an evolving "network model" of knowledge dissemination.

The findings have implications for future design of PLCs. They can be customized to specific goals and disciplines and may influence the pedagogy and policy of teacher professional development frameworks. Emerging innovative ideas and strategies within the PLCs enactment, suggest new avenues to explore in future implementation of PLCs. Taking a long-term view, continuing the collaboration of the practitioners with an academic team is important for advancing sustainable PLCs that promote professional development of teachers.

Acknowledgement We are grateful to the teacher-leaders of the PLCs who collaborated with us in designing and implementing the programs. The willingness to sincerely share with us their experience and insights were keystones of this effort. Special thanks to Hana Berger, Smadar Levy and Esty Magen, from the Physics team and to Miri Oren, Yifat Harrari and Marcel Frailich from the STEM team at the Weizmann Institute of Science.

We thank the Trump foundation for promoting and stimulating the PLCs' initiatives described in this chapter. We also thank Zvi Aricha and Aviva Breiner, national superintendents in the Ministry of Education (MOE), for the on-going support, and Miri Gottlieb and Tali Berglas-Shapiro from the MOE for their role in the national regulation of PLCs.

References

Akkerman, S. F., & Bakker, A. (2011). Boundary crossing and boundary objects. *Review of Educational Research, 81*(2), 132–169.

Akkerman, S. F., & Bruining, T. (2016). Multi-level boundary crossing in a professional development school partnership. *Journal of the Learning Sciences, 25*(2), 240–284.

Arcavi, A., & Isoda, M. (2007). Learning to listen: From historical sources to classroom practice. *Educational Studies in Mathematics, 66*(2), 111–129.

Ausubel, D. (1968). *Educational psychology: A cognitive view* (pp. 497–498). New York, NY: Holt, Rinehart & Winston.

Bauer, K., & Fischer, F. (2007). The educational research-practice interface revisited: A scripting perspective. *Educational Research and Evaluation, 13*(3), 221–236.

Benaya, Y., Yakobson, I., & Zadik, Y. (2013). *Professional learning community in school.* Avney Rosha Institute (in Hebrew).

Bolam, R., McMahon, A., Stoll, L., Thomas, S., Wallace, M., Greenwood, A., … Smith, M. (2005). *Creating and sustaining effective professional learning communities*. Bristol, UK: University of Bristol y Departament of Education and Skills.

Borko, H., Jacobs, J., & Koellner, K. (2010). Contemporary approaches to teacher professional development. In E. Baker, B. McGaw, & P. Peterson (Eds.), *International encyclopedia of education* (part 7, pp. 548–555, 3rd ed.). Oxford, UK: Elsevier.

Borko, H., Koellner, K., Jacobs, J., & Seago, N. (2011). Using video representations of teaching in practice-based professional development programs. *ZDM, 43*(1), 175–187.

Coburn, C. E., & Penuel, W. R. (2016). Research–practice partnerships in education outcomes, dynamics, and open questions. *Educational Researcher, 45*(1), 48–54. https://doi.org/10.3102/0013189X16631750

Cochran-smith, M., & Lytle, S. L. (2001). Beyond certainty: Taking an inquiry stance on practice. In A. Lieberman & L. Miller (Eds.), *Teachers caught in the action professional development that matters* (pp. 45–58). New York, NY: Teachers College Press.

Cochran-Smith, M., & Lytle, S. L. (2009). *Inquiry as stance: Practitioner research for the next generation*. New York, NY: Teachers College Press.

Collins, A. (1992). Toward a design science of education. In E. Lagemann & L. Shulman (Eds.), *Issues in education research: Problems and possibilities* (pp. 15–22). San Francisco, CA: Jossey-Bass.

Darling-Hammond, L., & Richardson, N. (2009). Research review/teacher learning: What matters? *Educational leadership, 66*(5), 46–53.

Donovan, M. S., & Bransford, J. D. (Eds.). (1999). *How students learn: history, mathematics and science in the classroom*. Committee on How People Learn, A Targeted Report for Teachers. Washington, DC: National Academies Press.

Donovan, S., Snow, C., & Daro, P. (2014). The SERP approach to problem-solving research, development, and implementation. In B. J. Fishman, W. R. Penuel, A. R. Allen, & B. H.

Cheng (Eds.), *Design-based implementation research: Theories, methods, and exemplars. National society for the study of education yearbook* (pp. 400–425). Teachers College Record: New York, NY.

DuFour, R. (2004). What is a “professional learning community”? *Educational leadership, 61*(8), 6–11.

Eylon, B. S., & Bagno, E. (1997). *Professional development of physics teachers through long-term in-service programs: The Israeli experience*. In AIP Conference Proceedings (Vol. 399, p. 299).

Eylon, B. S., & Bagno, E. (2006). Research-design model for professional development of teachers: Designing lessons with physics education research. *Physical Review Special Topics-Physics Education Research*, *2*, 020106-1–020106-14.

Eylon, B. S., Berger, H., & Bagno, E. (2008). An evidence based continuous professional development program on knowledge integration in physics: A study of teachers’ collective discourse. *International Journal of Science Education, 30*(5), 619–641.

Feiman-Nemser, S. (2001). *From preparation to practice: Designing a continuum to strengthen and sustain teaching*.

Gregson, J. A., & Sturko, P. A. (2007). Teachers as adult learners: Re-conceptualizing professional development. *MPAEA Journal of Adult Education, XXXVI*, 1–18.

Grossman, P., Wineburg, S., & Woolworth, S. (2001). Toward a theory of teacher community. *The Teachers College Record, 103*, 942–1012.

Harden, R. M., & Crosby, J. (2000). AMEE guide no 20: The good teacher is more than a lecturer: The twelve roles of the teacher. *Medical Teacher, 22*(4).

Harrison, C., Hofstein, A., Eylon, B. S., & Simon, S. (2008). Evidence-based professional development of science teachers in two countries. *International Journal of Research in Science Education, 30*(5), 577–591.

Hutchings, P., & Shulman, L. S. (1999). The scholarship of teaching: New elaborations, new developments. *Change: The Magazine of Higher Learning, 31*(5), 10–15.

Kali, Y. (2016). Transformative learning in design research: The story behind the scenes. In C. K. Looi, J. L. Polman, U. Cress, & P. Reimann (Eds.), *Transforming learning, empowering learners. The international conference of the learning sciences (ICLS) 2016* (Vol. 1, pp. 4–5). Singapore: International Society of the Learning Sciences.

Kali, Y., Eylon, B. S., McKenney, S., & Kidron, A. (2018). Design-centric research-practice partnerships: Three key lenses for building productive bridges between theory and practice. In M. Spector, B. Lockee, & M. Childress (Eds.), *Learning, design, and technology*. Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-319-17727-4_122-1

Knowles, M. S. (1990). *The adult learner: A neglected species*. Houston, TX: Gulf.

Koellner, K., Jacobs, J., & Borko, H. (2011). Mathematics professional development: Critical features for developing leadership skills and building teachers’ capacity. *Mathematics teacher education and development, 13*(1), 115–136.

Linn, M. C., & Eylon, B. S. (2006). Science education: Integrating views of learning and instruction. In P. A. Alexander & P. H. Winne (Eds.), *Handbook of educational psychology* (2nd ed., pp. 511–544). Mahwah, NJ: Lawrence Erlbaum Associates.

Linn, M. C., & Eylon, B. S. (2011). *Science learning and instruction: Taking advantage of technology to promote knowledge integration*. New York, NY: Routledge.

Little, J. W. (2012). Professional community and professional development in the learning- centered school. In M. Kooy & K. van Veen (Eds.), *Teacher learning that matters: Inter- national perspectives* (pp. 22–46). New York, NY: Routledge.

McKenney, S. (2016). Researcher-practitioner collaboration in educational design research: Processes, roles, values & expectations. In *Reflections on the learning sciences: Current perspectives in social and behavioral sciences* (pp. 155–188).

McKenney, S., & Pareja Roblin, N. (2018). Connecting research and practice: Teacher inquiry and design-based research. In *Second handbook of information technology in primary and secondary education* (pp. 1–14).

Milner-Bolotin, M., Fisher, H., & McDonald, A. (2013). Modeling active engagement pedagogy through classroom response systems in a physics teacher education course. *LUMAT: Research and Practice in Math, Science, and Technology Education, 1*(5), 523–542.

Penuel, W. R., Allen, A. R., Coburn, C. E., & Farrell, C. (2015). Conceptualizing research–practice partnerships as joint work at boundaries. *Journal of Education for Students Placed at Risk (JESPAR), 20*(1–2), 182–197.

Penuel, W. R., Bell, P., Bevan, B., Buffington, P., & Falk, J. (2016). Enhancing use of learning sciences research in planning for and supporting educational change: Leveraging and building social networks. *Journal of Educational Change, 17*(2), 251–278.

Pinto, A., & Cooper, J. (2016). In the pursuit of relevance – Mathematicians designing tasks for elementary school teachers. *International Journal of Research in Undergraduate Mathematics Education, 3*(2), 311–337.

Scherz, Z., Bialer, L., & Eylon, B. S. (2011). Towards accomplished practice in learning skills for science (LSS): The synergy between design and evaluation methodology in a reflective CPD programme. *Research in Science & Technological Education, 29*(1), 49–69.

Scherz, Z., Eylon, B., & Bialer, L. (2008). Professional development in Learning Skills for Science (LSS): The use of evidence-based framework. *International Journal of Research in Science Education, 30*(5), 643–668.

Scherz, Z., Eylon, B., & Yarden, A. (2018), *Science and Technology Professional Learning Communities Project*. Report to Trump Foundation, Weizmann Institute of Science, private communication (in Hebrew).

Shulman, L. S. (1997). *Communities of learners and communities of teachers*. Monographs of Mandel Institute.

Shulman, L. S. (1998). Theory, practice, and the education of professionals. *The Elementary School Journal, 98*(5), 511–526.

Shulman, L. S. (2011). Feature essays: The scholarship of teaching and learning: A personal account and reflection. *International Journal of the Scholarship of Teaching and Learning, 5*(1), Article 30.

Strauss, N. (Ed.). (2017). *Insights from past initiatives to promote science education in Israel – Learning from selected issues*. Project Report. Jerusalem, Israel: The Initiative for Applied Education Research, Israel Academy of Sciences and Humanities.

Timperley, H., Wilson, A., Barrar, H., & Fung, I. (2008). *Teacher professional learning and development*. Wellington, New Zealand: Ministry of Education.

Trigwell, K., Martin, E., Benjamin, J., & Prosser, M. (2000). Scholarship of teaching: A model. *Higher Education Research & Development, 19*(2), 155–168.

van Driel, J. H., Meirink, J. A., van Veen, K., & Zwart, R. C. (2012). Current trends and missing links in studies on teacher professional development in science education: a review of design features and quality of research. *Studies in Science Education, 48*(2), 129–160.

Vescio, V., Ross, D., & Adams, A. (2008). A review of research on the impact of professional learning communities on teaching practice and student learning. *Teaching and teacher education, 24*(1), 80–91.

Whitcomb, J., Borko, H., & Liston, D. (2009). Growing Talent. *Journal of Teacher Education, 60*(3), 207–212.

Bat-Sheva Eylon is a Professor in the Department of Science Teaching at the Weizmann Institute of Science (WIS) in Israel. She has an MSc in physics from WIS and a PhD in Science and Mathematics Education from UC Berkeley. Her main areas of research lie in the learning and teaching of physics in grades 7–12 and the long-term professional development of teachers and teacher-educators in the areas of physics and other sciences. She has designed and operated a variety of research-based professional development frameworks for teachers such as professional learning communities implemented throughout Israel. The Knowledge Integration Perspective on Teaching and Learning, developed and researched with peers, has served as a conceptual framework for many of these activities, as well as for curriculum development programs and technological innovations. Currently she chairs the Vidactics program and co-chairs the Personalized Teaching and Learning (PeTeL) initiative as well as the Rothschild-Weizmann Program for Excellence in Science Teaching. Bat-Sheva is a Fellow of the AAAS. In 2015 she received the EMET prize in education.

Dr. Zahava Scherz is a faculty member, of the Department of Science Education at the Weizmann Institute of Science. She completed her academic studies at the Hebrew University where she obtained a bachelor's degree in chemistry, a master's degree in biophysics and a doctorate in science education. Her research thorough the years was in the fields of artificial intelligence and education, learning skills in science, attitudes and perceptions of students towards science, professional development of teachers and the development of learning communities for science teachers. With colleagues and students she developed the program "LSS – Learning Skills for Science" that has been adopted and taught in thousands of schools in the UK and other countries such Brazil, Singapore and Canada. She founded and directed the National Teachers' Center for STEM Teachers in for 15 years Israel and co-chairs Professional Learning Communities national project for STEM teachers and leading teacher. She taught many graduate courses and supervises graduate students.

Dr. Esther Bagno is Senior Scientist in the Department of Science Teaching at the Weizmann Institute of Science. She has a BSc in Physics and Mathematics from the Bar Ilan University and an MSc and PhD in Science Education from the Weizmann Institute of Science.

Her main areas of practice and research involve high-school students' physics learning and physics teachers' professional development. She developed learning materials for students emphasizing key concepts and principles in physics, and integrated ideas from the learning sciences into the learning and teaching of physics.

She headed the National Center of Physics Teachers in Israel and the Professional Learning Communities (PLCs) of physics teachers spread all over the country. She teaches graduate courses and supervises graduate students.

On Teaching and Learning Mathematics – Technologies

Nathalie Sinclair

1 Introduction

In his book *Lines: A brief history,* the anthropologist Tim Ingold (2007) studies the way in which the very idea of *line* functions metaphorically in Western society. He argues that it is so deep and entrenched that we often find ourselves using it, usually subconsciously, to describe a wide range of phenomena. This is evident in education through the variety of words associated with lines, such as trajectories, paths, roads, trails, courses and routes. These words connote linearity, straightness, unidirectionality and one-dimensionality. Ingold distinguishes two ways of thinking about lines: one as transporting and the other as wayfaring. In the former, we might think of going from point A to point B, which implies a certain path connecting the two locations. In the latter, the line is what one makes as one moves; there is no path independent of the travelling. Transposed to a theory of learning, the former would tend to conceive of learning as a sequence of journeys one might make from one concept to the next—you have learned once you have arrived at B; the latter would focus on the act of tracing, on learning as process, on the territory being explored—you are learning as you are moving. The former involves reaching successive destinations while the latter involves creating paths.

I find these ideas useful for thinking about the teaching and learning of mathematics broadly speaking, but also about the role of digital technology in mathematics education. Transport lines can be dangerous. They can begin as imaginary paths to be followed, but once drawn, they can become troughs that are hard to escape. Research in the use of digital technologies can sometimes reinforce troughs, when it focuses more on how technologies can increase the speed of the journey, rather than on the unexpected conceptual shifts that can be occasioned. Indeed, what we know from the research on the use of digital technologies, is that they can often

---

N. Sinclair (✉)
Simon Fraser University, Burnaby, Canada
e-mail: nathsinc@sfu.ca

Y. Ben-David Kolikant et al. (eds.), *STEM Teachers and Teaching in the Digital Era*, https://doi.org/10.1007/978-3-030-29396-3_6

change the nature of concepts—or, more precisely, the possibilities of interaction between learners and concepts—in such a way that can, for example, make division precede multiplication (Confrey, 1994); place value precede addition (Coles & Sinclair, 2017); and, that can enable children to "skip" van Hiele levels of learning to reason in geometry (Battista, 2007).

Tools change concepts. Not only do particular mathematical concepts give rise to new tools, but particular tools give rise to new concepts, as Rotman (2003) makes clear when he writes that,

> Machines and mathematics are engaged in a two-way traffic that forms a co-evolutionary loop, so that, for example, a machine like the lever depends on the mathematics of ratios and conversely the theory of ratios and rational numbers is consolidated and motivated by the concrete representations levers provide. (p. 1675)

Tools also change learning. They can change, for example, what is taken to be concrete or abstract, as Wilensky (1991) has argued in relation to the use of Turtle geometry. They can also change the sensorimotor activities of the body on which conceptual understanding is based (Lakoff & Núñez, 2000) as in the particular way of moving one's hands when using an abacus (Bartolini-Bussi & Boni, 2003) or the particular way of dragging an object when exploring a geometric invariance (Arzarello, Olivero, & Robutti, 2002). But managing this change, as a teacher, is very challenging. Not only does it go against the transport-driven organization of textbooks, standards and curricula, it also disrupts the common belief that digital technologies are crutches—that can later be 'removed'— for making particular mathematics topics (in their pencil-and-paper incarnations) easier to learn.

Most of my own research has focussed on learning with digital technologies and has documented the discursive, gestural, affective and conceptual changes that these technologies and their associated tasks have enabled. However, in this chapter, I focus on teaching with digital technology. I will be drawing on two different research projects. The first is a joint project with colleagues in Italy aimed at trying to develop strategies for better supporting teachers' use of dynamic geometry environments (DGEs) at the elementary school level. The second involves the experiences of teachers in a Master's programme using a multitouch app called *TouchCounts* that focuses on early number learning. However, I begin by providing a macro-level overview of the way that technology is currently conceived in relation to mathematics and to learning. I then use this to motivate some new approaches to our thinking about mathematical concepts, which will provide the basis for the subsequent discussion of the research project mentioned above.

2 The Place of Technology in Teaching and Learning

In this section I first consider existing theories of mathematics learning and the way they position technology in the teaching and learning process. I then outline some new directions in learning theories that see the role of tools in a very different light.

2.1 Tools as Dispensable Crutches

The idea of mathematics learning as a developmental trajectory that starts with 'the basics' and becomes more advanced over the years fits well with the transport metaphor. It also echoes the prevalent Piagetian assumptions found within mathematics education, amongst both researchers and teachers, which is that mathematical concepts can be naturally ordered in a continuum from concrete to abstract. In this perspective, learners are seen as moving from point A ('having' a particular concept such as addition) to point B ('acquiring' a different concept such as multiplication) in an interaction that is primarily propelled by time. From a more Vygotsian perspective, language and tools are seen to be centrally important in learning, as are the expert interlocutor (the teacher), so that the movement from A to B is mediated by interventions that are nonetheless aimed at assuring the arrival at B, which is the targeted cultural knowledge.

In the learning trajectory research, which has gained much traction in the United States, there is an espoused emphasis on Vygotsky, but the underlying Piaget (1954) influences are evident (for example, Daro, Mosher, & Corcoran, 2011). A hypothetical learning trajectory includes the learning goal, the learning activities, and the hypothetical learning processes. Researchers engaged in this work recognize that there may be multiple ways of getting from A to B (e.g., Barrett & Battista, 2011), and that the tasks used can affect the particular paths that students might travel along. However, these researchers continue to identify and disseminate findings that do not specify the tools used in moving from A to B. The tasks, on the other hand, are reported in some detail, perhaps because they can easily be shared, in print, with a wide variety of educators. On the other hand, the particular moves that a teacher makes are not as easily shared, and thus feature less centrally. And the tools fade away in importance, at least in part due to the assumptions that many educators make about tools—namely, they are crutches and do not matter in the end, after point B has been reached. Indeed, if digital technologies were used in any of the tasks studied by researchers, it is assumed that the stepping stones from one concept to another could be made *no matter what* technology was used—but the default technology is almost always paper and pencil. This point of view contradicts the Vygotskian premise, but also reifies a certain vision of mathematics teaching and learning that makes it more difficult for digital technologies to be taken up at scale—and thus contributes to the continued debate around 'the basics' (see Roth, 2008).

In the Vygotskian-inspired theory of semiotic mediation (Bartolini Bussi & Mariotti, 2008), where there is a specific attempt to theorise the use of non-digital and digital technologies in mathematics teaching and learning, tools take on a central mediating role. Indeed, they are seen as necessary for enabling learners to encounter and internalise mathematical concepts, which are seen as being not directly available to the human senses. In this theory, the roles of the teacher, who handles the mediation process (and does not just choose the tasks, as in the learning trajectory research), and of the tasks, which enable the production of signs by the learner, are also treated very seriously.

I have evoked important shifts across different theoretical paradigms on mathematics learning, while also highlighting some similarities. In each case, the learner is seen as moving along some kind of path, even if it is a hypothesized one, and doing so in interaction with teachers, tools and tasks, in order to arrive as a predetermined point B, *which remains unchanged by the tool, task, teacher or learner*. Similarly, across all these perspectives, the learner, the concept, the tool, the mathematics, the tasks and the teacher are seen as *merely* interdependent—that is, they exist in isolation from each other even if they do interact.

2.2 Tools as Ontological Determinants

Enactivism offers quite a different perspective on learning and on the nature of the interaction. For example, enactivism calls into question the assumed distinction between an individual and a tool, arguing that the human should be seen as embodied, extended and distributed. Imagine a blind man walking around a city street with a cane. As Bateson (1972) asks: "Where does the blind man's self begin? At the tip of the stick? At the handle of the stick? Or at some point halfway up the stick?" He argued that to draw a fixed boundary between the man and the cane "is to cut off a part of the systemic circuit which determines the blind man's locomotion" (p. 318). In this distributed, systems view, it makes more sense to think of the student/tool as a unit, instead of delimiting a student's actions and thoughts to the boundary between the student's hand and the abacus she manipulates or the screen she touches. Rather than seeing the tool as an intermediary between the learner and the mathematics, an enactivist sees them as an imbricated whole.

More radically still, de Freitas and Sinclair (2014) propose to extent the ontological shift to mathematics itself, so that the mathematical concept is no longer independent of the student/tool system, but part of it, entangled with it. Their proposal draws both on the ideas of the philosopher of mathematics Gilles Châtelet (2000), on Rotman's (2008) materialist reading of the history of mathematics and on recent theories of new materialism (Barad, 2007). de Freitas and Sinclair show how Barad's (2007) concept of intra-action can be used in the context of mathematics education to highlight the ontological entanglement of concepts, tools and humans, and show how they are mutually constitutive rather than being independently interacting. Rather than inter-acting, which is how we might view the relationship between a compass and a circle, intra-acting suggests that the very concept of circle that emerges from the relation is fundamentally constitude by the tool. In this case, it might make more sense to talk about the compass-circle instead of just the circle (which ignores its technological genesis). In this perspective, there is not a predetermined B at which to arrive. At least, there is no B independently awaiting the arrival of the learner, in the way that Jerusalem might await my arrival, without having to change anything about itself.

Already in Artigue, 2002, Artigue had argued that the problem with doing comparative research in mathematics education—comparing the use of digital technology with paper-and-pencil—is that both what is learned and how it is learned depends on the technology being used and thus makes comparison almost impossible—and all the more so if the technology in question is doing something truly different. But this point does not get sufficiently acknowledged, even in studies that use the theoretical tools that she espoused, namely the instrumental genesis approach. If the problem remains unaddressed at the level of research on student learning, then it is even less visible in the research on teachers' use of digital technology. For example, in the descriptive model proposed by Mishra and Koehler (2006), which adds 'Technology" to the Venn diagram of pedagogical content knowledge (PCK), there is a sense in which the technology and the mathematics relate (in their overlap) but the focus is an epistemological rather than ontological one (i.e., what teachers know about mathematics and technology, rather than how either of them are transformed). In the more nuanced and analytic framework proposed by Ruthven (2014), which identifies five structuring features of classroom practice that shape the way teachers integrate new technologies (the working environment, the resource system, the activity format, the time economy and the curriculum script), this is more attention to the manifold ways in which the use of digital technology can affect teaching practice. Nevertheless, mathematics remains static, unchanged, as the set of fixed concepts whose learning can be supported by the teacher and the technologies she chooses to use in her classroom.

Therefore, even theories that emerge from the context of digital technology use—and which are thus more well-disposed to attend to the interplay between school mathematics concepts and technology, both for learning and for teaching—fail to attend sufficiently to the way tools can change, mould mathematical concepts. And since existing paper-and-pencil technology is perfectly suited to the school mathematics concepts that currently populate curricula, it is not surprising that teachers have not taken up the use of technology as was expected and predicted. Indeed, while standards in most countries may have language that includes reference to the importance or usefulness of digital technology, the actual concepts that are listed, and the order in which they are listed, are determined in a way that is absolutely independent of any particular digital technology *other than paper and pencil*. School mathematics is basically stuck in the technological infrastructure of 600 AD, which gave rise to Arabic numbers. For example, in the area of geometry, a curriculum or textbook that asks students to engage in geometric construction by drawing figures that have numerically determined side lengths and angle measures is anti-dynamic. This, after two decades of research showing the pedagogical benefits of using DGEs in the teaching and learning of geometry.

In the next section, I consider the potential for new theoretical insights to shift our understanding of how better to support teachers' use of digital technology in the mathematics classroom. I offer two examples: one taken from an ongoing project with colleagues in Italy on the use of DGEs in the elementary school; the other from research involving elementary school teachers and early number learning using a multi-touch app called *TouchCounts*. The first example focuses on how working with teachers might productively focus on the *ontological* aspects of mathematical concepts. The second, which is inspired by some of Tahta's (1998) ideas, focuses on disrupting the deeply engrained assumptions that teachers have on the importance of beginning the learning process in the concrete and metaphorical. Both of these methods take concepts to be generative devices, as per the perspective of de Freitas and Sinclair (2017). They both also involve challenging the seduction of the transport metaphor.

3 Teachers and Teaching in the Digital Era

In this chapter, I argue that an important ingredient in supporting teachers in an era of change—by which I mean supporting their use of high-quality digital technologies—begins by shifting away from the transport metaphor of learning that involves moving from pre-determined concept to the next, in a way that ignores the particular way in which tools and concepts intra-act. In order to do this, I suggest that we need to change how we think about mathematical concepts, so that we attend not only to their logical nature but also their ontological nature. Although not situated within research involving digital technologies, Brent Davis and his colleagues have also begun to approach their work with teachers by focusing on concepts—see Davis and Renert (2014) for an example involving multiplication.

3.1 Teachers Re-Thinking Concepts

Research on teachers' use of digital technologies in the mathematics classroom has shown over and over again that teachers tend to use the technologies in very different ways than do the researchers. Laborde (2001), for example, showed how novice teachers, in particular, tended to use a DGE to do things that were very similar to what they would normally do with paper-and-pencil technology. Indeed, it was based on studies of secondary school teachers' use of DGEs that Ruthven, Hennessey and Deaney (2008) developed the framework mentioned in the previous section to try to provide insight into the many challenges that can prevent teachers from using digital technologies in ways that transform their usual approaches.

As part of a project with colleagues in Italy, Anna Baccaglini-Frank and Pietro di Martino, we have been trying to find new ways of supporting elementary school teachers' use of DGE-based activities (see Baccaglini-Frank, Di Martino, & Sinclair, 2018). We started with activities involving line symmetry that had been developed for a classroom intervention research study whose results are reported in Ng and Sinclair (2015). The materials had been made available on-line, along with guiding questions for the teachers and sample student work (see http://www.sfu.ca/geometry4yl/symmetry.html), but we knew that these would not provide sufficient support for the teachers. The pre-made sketches, designed in *Sketchpad*, consist of eighteen

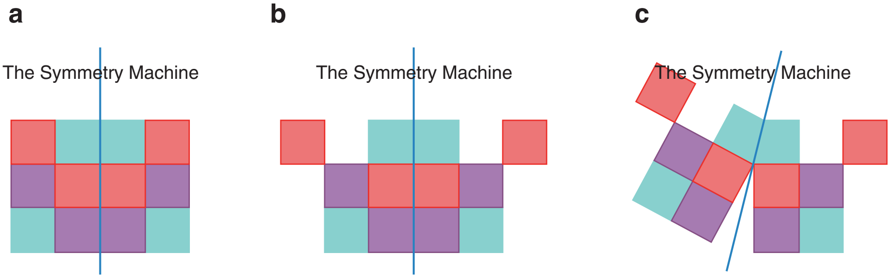


Fig. 1 (**a**) Discrete symmetry machine; (**b**) After dragging one square; (**c**) Oblique line of symmetry

coloured squares arranged symmetrically around a line of symmetry (see Fig. 1a). These squares move discretely on a square grid background. Dragging any square on one side of the line of symmetry will also move the corresponding square on the other side of the line of symmetry (see Fig. 1b).[1] The discrete motion, as well as the use of the grid, was found to help the children in the study attend to the distance between corresponding squares and the line of symmetry. Dragging the line of symmetry either by translating the line as a whole or by rotating it around one of its two defining points can create horizontal or oblique lines of symmetry (see Fig. 1c).

For the research project, we worked with three italian elementary school teachers. It was decided that Anna would teach a grade 2 class and video-tape the lesson so that the three teachers would be able to view the video and, subsequently, teach their own students (the lessons the teachers taught were also video-taped). Anna and Pietro also had a face-to-face meeting with the teachers beforehand and discussed with them some of the decisions that had gone into the re-design of the sketches that they implemented. We conceptualised these sketches as boundary objects (Star & Griesemer, 1989), that is, specific objects that are used in two communities—the research community and the classroom teaching community. After the teachers had taught the lesson, there was a second round of interviews during which the teachers were asked to debrief on their experiences.

Before describing some of the results of this study, I consider briefly the question of the nature of a mathematical concept, since this question will be of central importance in understanding the approach we took in the study. Succinctly put, de Freitas and Sinclair (2017) argue that any mathematical object can function both logically and ontologically. Take a circle, for example. The circle, as the set of points equidistant from a given centre, *realises the possibility* of the circle, that is, complies with the action of determining the set of points. In instantiating the definition of the circle, we abide by the logical necessity given by the definition. But there is also another kind of determination that involves an *actualising of the virtual* rather than a *realising of the possible*. The circle is *also* materially produced by the trace of a

---

[1] Readers are encouraged to interact with the sketch themselves at: http://www.sfu.ca/content/dam/sfu/geometry4yl/sketchpadfiles/Broken%20Block%20Symmetry%202/

point constantly being pulled to a centre. As an emerging figure, this circle has an inherent mobility. The first definition performs the logical necessity of the circle, the seeming a-contextual universality of the concept, while the activity of generating the circle is just as important in *determining* its existence. In other words, the concept of circle *lives in* the material as much as it *lives by* logical constraints. The importance of the ontological aspect of the concept is articulated by de Freitas and Sinclair as follows:

> When the concept is used only as a logical tool, or as an object or relation with a finite set of properties, the ontological aspect (actualizing the virtual) is abandoned, and activity is reduced to adhering either to naming exercises […] or to applications of the concept as a rule or logical constraint. In such cases, the ossified concept fails to sustain the mobility and potentiality which is its nature. (p. 84)

Of course, insofar as mathematics aims to be a self-authenticating method of inquiry, logic will always play a pivotal role. Yet, the empirical dimension of mathematics always introduces the ontological factor. In our case, we were focusing on the concept of line symmetry, which the teachers usually taught by first defining symmetry and then inviting the students to paint one half of a piece of paper and fold it over in order to produce a symmetric design. Evidently, the teachers were plying the logical functioning of line symmetry and the folding of the paper furthered the realising of the possible. From our analysis of the data, there were two significant aspects to the teachers' experiences in our study—one occurred during the pre-teaching discussion and the other while watching the video-taped lesson by Anna —that seemed to enable them to re-think the concept of line symmetry as it is materially produced in the DGE.

The first aspect was related to a discussion of the design of the sketch, during which Anna and Pietro talked about how the snap-to-point functionality of the sketch did not work very well in the case where the line was neither horizontal nor vertical. They decided to remove this functionality so that the behaviour of the draggable objects would be consistent no matter how the line of symmetry was inclined. They also opted to use a circle instead of a square, again in order to not privilege the symmetries of the horizontal and vertical orientations of the line of symmetry. During the discussion, the teachers expressed surprise at the fact that so much consideration was being devoted to the behaviour of the objects, which did not at first seem to them to be that important for teaching children about line symmetry. The impact of this discussion became more evident during the debrief discussion, when the teachers explained how it had helped them direct the children's attention to the relation of the motion of the objects on the screen.

If only the logical functioning of symmetry was at stake, then the behaviour of the sketch would not matter, because it would be seen, simply, as a physical instantiation of a fixed concept—which had been, for the teachers, about the property of a design as a whole, rather than a more functional relation between an input and an output. However, what the teachers were hearing through the discussion was how the concept of symmetry was also *living in* the behaviour of the sketch. In this indeterminate, material world, as became evident during the three different lessons, there could be an *actualising of the virtual*, that is the emergence of new concepts that are not logically determined. For example, the teacher and children in one class began attending to the infinite number of points where the circles could meet—so that the line of symmetry was actualised as the infinite locations of circle-meeting. The very fact that the teacher was able to orchestrate classroom discussion around such an idea is evidence that she was allowing the concept of symmetry to operate ontologically, putting it to work in engendering new concepts.

Another example of this actualising of the virtual, which we traced back to the discussion of the design of the sketch, arose in all three classrooms and related to the inclined line of symmetry. The teachers explained that in their usual teaching of symmetry, they only considered horizontal and vertical lines of symmetry. In discussing the design of the sketch and the modifications made by Anna and Pietro, they came to understand that horizontal and vertical lines of symmetry were special cases of the more general line of symmetry. Not only did each of the teachers actually incline the line of symmetry in their lessons (making them diagonal instead of horiztonal, as Anna had done), they also led the children to describe the movements on the screen as being *with respect* to the line of symmetry, which enabled the students to describe the movement of the circles in ways that could be generalised to any particular inclination of the line of symmetry. For example, if the line of symmetry is vertical, then the children could describe the movement of the circle as going up and down or right and left, but such directional language is less useful when the line of symmetry is oblique. In that case, it makes more sense to speak of the movement of the circle as being away from or along the line of symmetry—a way of talking that can also describe the particular case of a vertical line of symmetry. We see this as an actualising of the virtual because it arises both out the movement of the objects on the screen and the reckoning with the infinite possibilities of behaviour that the different inclinations of the line of symmetry give rise to.

The second experience that seemed central to the teachers' experiences relates to their watching of the video of Anna teaching. Each one of the teachers expressed surprise at the fact that Anna never once defined or described symmetry, but instead let the concept of symmetry emerge from the interactions with the children and the sketches. Anna's interventions during the lessons were aimed at inviting the children to attend to the behaviour of the objects on the sketch, especially to what was changing and what was remaining invariant. It seems obvious that if the definition is given in advance, then the mathematical activity will be geared towards realising the possible, that is, towards the logical functioning of the concept of line symmetry. By withholding the definition, and following Anna in focusing on the behaviour of the sketch, the teachers shifted the emphasis. In one sense, using Ruthven's framework, the teachers completely changed their activity scripts by essentially reversing the normal order of activity in the classroom. But simply stating this does not help explain *how* this occurred. What is significant is that the teachers changed their thinking about the mathematics at stake and began to conceptualise symmetry as being empirically intertwined with the DGE sketches. From an Ingold (2007) point of view, the teachers were less focused on using the technology to enable the children to learn a certain fixed concept (what symmetry looks like), and instead enabling their own concept of line symmetry to function ontologically, which led the children/teacher/software assemblage in novel directions.

3.2 Teachers Re-Thinking Mathematical Meaning

The second example I will describe involves elementary school teachers who are pursuing a Master's degree in mathematics education. One of their courses focuses specifically on the use of digital technology in mathematics teaching and learning and in it, they are introduced to several different technologies. In this example, I focus on one of the classes taught late in the semester when I introduced the multi-touch iPad app *TouchCounts* (Jackiw & Sinclair, 2014), which was designed to support early number learning, and so is most relevant to the K-2 grade range. Rather than speak to any changes in terms of the teachers' practices, my discussion will focus on insights into some of the mathematical issues at play in teachers' use of digital technology in the classroom.

In the brief description of *TouchCounts* that follows, it should become obvious that it is designed to enable children to work with both the ordinal and cardinal dimensions of number, and that counting involves not only number names and objects, but also centrally involves number symbols. Further counting can be seen as being both transitive and intransitive, where intransitive counting is ordinal counting that does not count things. After describing the app, I will share an exchange that I had with one of the teachers in the program—an exchange that has occurred many times, with slight variations, with other elementary school teachers—and use that as a springboard to propose new ways of working with teachers in inservice situations.

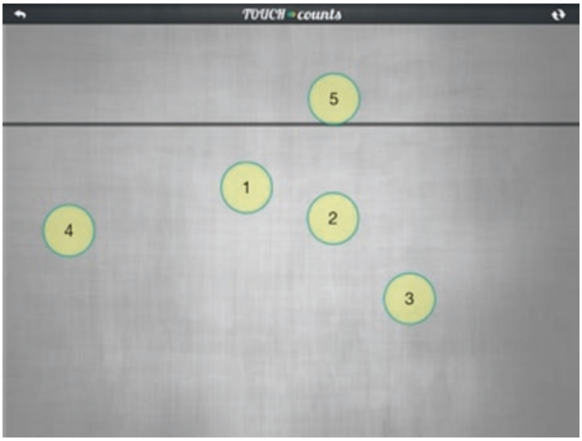
TouchCounts is a free, multi-touch app (www.touchcounts.ca), which has two worlds, called Enumerating and Operating. In the Enumerating world, each time a student touches the screen with one finger, one object (a yellow disc) is created on the screen and, simultaneously, one number name is said aloud. The number-names are said in order (one, two, three, four, etc.) and the symbols appear in order (1, 2, 3, 4, etc.). In this way *TouchCounts* creates a one-to-one-to-one-to-one correspondence among *touch, number-name, screen object* and *numeral*. When 'gravity'[2] is turned "on", a "shelf" (a horizontal) appears on the screen; when a tap is made below the shelf, the yellow disc falls away under the "force of gravity"; and, when a tap occurs above the shelf, the yellow disc is "caught" and stays on the shelf. In Fig. 2, there have been four taps below the shelf and the fifth tap above the shelf.

In the Operating world, tapping on the screen creates autonomous numbered sets, which we refer to as *herds*. If a student places one or several fingers on the screen, a large disc is created that encompasses all the fingers touching the screen

---

[2] The gravity mode makes the screen objects fall vertically down the screen and disappear. When the gravity mode is turned off, the screen objects remain on visible until the reset button is pressed.

Fig. 2 Counting to 5



and includes a numeral corresponding to the combined number of those fingers. At the same time, every one of the fingers in contact with the screen creates its own much smaller (and unnumbered) disc, centred on each fingertip. When the fingers are lifted off the screen, the numeral is spoken aloud and the smaller discs are then lassoed into a herd and arranged regularly around the inner circumference of the big disc (Fig. 3a shows herds of 3 and 4).

After two or more such arrangements have been produced (as in Fig. 3b) they can either be pinched together (addition) or ‘unpinched’ (subtraction or partition). Dynamically, they then become one herd that contains the ‘digital’ counters from each previous herd, thus adding them together. The new herd is labelled with the associated numeral of the sum (Fig. 3c), which *TouchCounts* then announces aloud. Moreover, the new herd keeps a trace of the previous herds, which can be seen by means of the differentiated colours of the individual component small discs.

The following exchange took place shortly after I had introduced *TouchCounts* to the teachers and then shown them a video in which a group of four 5-year-old children had spent over 10 minutes trying to put 100 (and no other number) on the shelf (this involves tapping 99 times below the shelf before tapping a 100th time above the shelf—recall that the curriculum for children at this age usually focuses on numbers between 1 and 20). After failing many times, the children succeeded. Since tapping 99 times is quite time consuming, the children used multiple fingers simultaneously to create a very big number and repeated this process. In their first attempt, the children made 107, but they did not seem to know that they had surpassed 100—or, more precisely, they kept adding more herds in the hope of making 100. For example, at a certain point, after putting 107 on the shelf, one boy explained that they just needed to continue and make another 0.

In the video, it seems that the children eventually came to understand that proceeding more slowly once they had reached the nineties would enable them to attain their goal; in particular, they came to focus on the importance of 99. Although I was

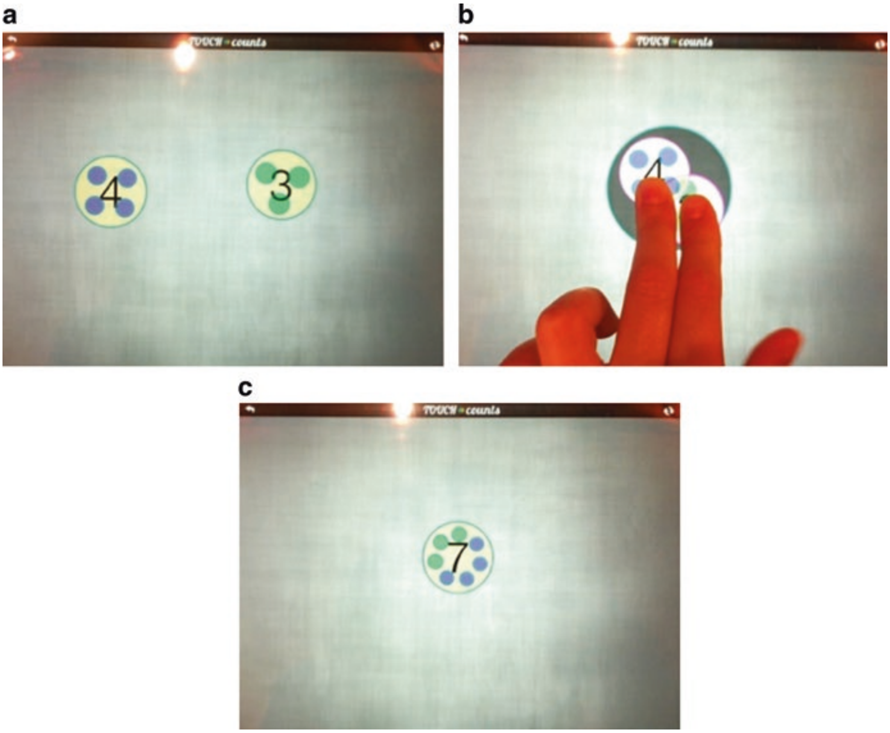


Fig. 3 (**a**) The herds; (**b**) Pinching two herds together; (**c**) The sum of two herds

presenting this as an accomplishment, one of the teachers in the class seemed unconvinced:

Teacher:	The kids need to be able to see what 100 really is.
Nathalie:	They can get a different sense of 100 by seeing how long it takes to get to 100 by counting though.
Teacher:	Yes, but that doesn't help them estimate what 100 really looks like, like when you have to solve a problem involving 100 things.
Nathalie:	Yes, for estimation, I can see why you say that. But I think there are other situations in which you might not need to know what 100 really looks like. Imagine, for example, you were asked what comes after 124.
Teacher:	But the kids need to be able to know that 124 is 100 and 20 and 4.

What is significant in this exchange is the teacher's focus on what 100 "really is." It soon became obvious that for her, the meaning of 100 derives from its cardinality. In other words, for her, the number 100 *means* a set of 100 things that can be counted up. This is not the only meaning of 100. For example, a more ordinal conception of 100 would take its meaning from its relation with what precedes it (99) and follows it (101), as well as the symbolic structure of the numeral itself. Someone who knows 100 this way would be able to tell you what number comes after 200 because of its symbolic structure. The teacher's own prior experiences, as well as the curriculum itself, which takes cardinality to be the more basic aspect of number (see Coles, 2014), could easily account for her assumptions about the meaning of 100. However, there is another underlying issue at stake.

When the teacher speaks of what 100 "really is," she is referring to the concrete instantiation of 100 through the metaphor of objects (such as counters). Similarly, her description of what it means to know 124 evokes a representation such as Dienes blocks, which is also cardinal in nature. In order for teachers like this one to make effective use of *TouchCounts*, they would not only need to develop a different conception of number (a more ordinal one) but also to shift assumptions about children's need to begin their learning in the concrete. By using the word 'concrete,' I do not necessarily mean the physical, because there are many apps that use digital counters too. Rather, I am taking the concrete here to centrally involve the metaphorical.

In a discussion about the challenges involved in teaching and learning arithmetic, Tahta (1998) distinguishes between 'metaphoric' and 'metonymic' ways of accessing number. A metaphor replaces one thing with another thing to help make sense of the original (e.g., number '2' becomes a rod of length 2 cm or two counters). Metaphoric ways of approaching number, therefore, might involve an abacus, a ten-frame, rods, or any other direct re-presentations of numbers. The models, it is hoped, shed light on what number 'is'. A metonym is a substititon of the name of an attribute or adjunct for that of the thing meant. Metonymy is thus about 'part-whole' relations, where one aspect of a thing can be a substitute for the whole (e.g., the number '2' can be associated with the act of matching two of the same rod against a single rod of equivalent length). The numeral (symbol) or the number-word is another *name* for number, not its 'meaning', but work with number names and the verbal code can still be meaning-*ful*. Tahta argued that there is too much metaphoric work in early number, which also seems to focus almost exclusively on cardinality, and not enough metonymic work, which seems more ordinal in nature. The question of meaning relates to the assumption that a metaphor carries more meaning in that it is another thing that is physical and familiar—it is about identity and this seems to be the concern of the teacher in the exchange quoted above. A metonym rests more on difference, on the relation between things, than on identity.

Coming back to technology, one of its central affordances in mathematics education is to enable learners to operate directly on mathematics, rather than through metaphors. In DGEs, for example, learners act directly on the geometric shapes, morphing them according to the constraints of their constructions. No longer does one plastic triangle or diagram represent the general idea of triangle; instead, the triangle *lives in* the dynamic manipulation. In *TouchCounts*, children also act directly on the numbers.

In working with teachers in the Master's program, I have found that one way of increasing their comfort with a more metonymic way of working has been to highlight the important role that children's bodies—and especially their hands and fingers—are playing in their interactions with *TouchCounts*. This bodily engagement—which, following Bateson (1972), we see as an embodied extension with the tool—seems to humanise the interaction sufficiently and thus distance it from the mechanical activity of symbol manipulation that the teachers want to avoid. Similarly, showing the teachers video clips from our research studies in which the children are evidently engaged in curiosity-driven activities such as putting 100 on the shelf, helps the teachers reframe the children's activities in terms of fluency development. Indeed, this view is consonant with Serres' (2011) assertion that imitation is the origin of knowledge: "there is nothing in knowledge which has not been first in the entire body, whose gestural metamorphoses, mobile postures, very evolution imitate all that surrounds it" (p. 70). Serres is suggesting that the origin of knowledge is *not* understanding, which is about explanation and inference (metaphor), but instead is in the building of memory in the body, through gestures and movement. While this assertion sits well with the elementary school teachers with whom I have worked, I am not sure it would find as much resonance for secondary school teachers, whose disciplinary commitments often preclude the relevance of the body in mathematics knowledge.

An additional advantage of highlighting the body knowledge involved in working with *TouchCounts* is that it provides teachers with visible signs to look for in trying to understand and assess their students' thinking. A child making the pinching gesture while trying to explain the result of a sum helps teachers see how that child has developed new ways of moving, and thus new ways of thinking.

4 Towards a Vision of Mathematics-Technologies Teaching

The main claim that I have made in this chapter is that the transformational use of digital technologies will not be possible until we reckon adequately with the ways in which mathematics and tools are intertwined. Roth (2008) makes a similar argument, drawing on cultural-historical activity theory, but without the material perspective. Roth shows how the history of mathematics has involved the development of tools that enable the automatisation of certain tasks, such as computation, in order to permit people to focus attention on harder tasks. In other words, "[i]f tools embody crystallized skills, and if tools develop with culture, then we no longer require the same skills when tools develop and old tools are abandoned to technological museums" (p. 278). Roth's argument can help us understand why we may no longer wish to teach "the basics" or algorithms such as long division. But in wanting to abandon such skills and algorithms, he may not appreciate the way in which that will also mean that teachers must abandon some of their cherished concepts, *because concepts co-evolve with tools*. What is needed is a more nuanced way of helping teachers think about what can be meant by division in an era of calculators or even of *TouchCounts*.

In this chapter, I proposed two different strategies for helping teachers appreciate the transformative nature of certain digital technologies as they relate to mathematical concepts. But if teachers are bound to curricula that privilege paper-and-pencil concepts, such strategies may be irrelevant. However, with the growing interest in curriculum thinking that emphasises competencies, as in the new British Columbia mathematics curriculum, such strategies may find purchase. Indeed, competency-oriented curricula are less constrained by transport metaphor thinking, where the goal is to arrive at particular destinateions, particular conceptual acquisitions, and more open to wayfaring, to the process of exploring, manipulating, expressing and demonstrating mathematical objects and relations. Such processes centrally involve sensorimotor actions and actions with tools of many kinds. As articulated by many mathematics education researchers with interests in the bodily basis of understanding (see de Freitas & Sinclair, 2014), the main reason for using digital technologies is neither to concretize a concept nor to excavate the ideas built into objects, but to introduce new actions and therefore: *to move*. That is, one's senses of shape, quantity, proportion and so on have more to do with "*structured acts of moving* than with *acts of moving structures*" (Ng, Sinclair, & Davis, 2018). In both the examples I described in this chapter, the aim was to highlight the way in which the particular digital technology was not only about (re)presenting existing mathematical concepts, but was about changing what learners do with their fingers and hands, in the process occasioning opportunities for them to expand and interweave their repertoires of mathematically relevant structures.

References

Artigue, M. (2002). Learning mathematics in a CAS environment: The genesis of a reflection about instrumentation and the dialectics between technical and conceptual work. *International Journal of Computers for Mathematical Learning, 7*, 245–274.

Arzarello, F., Olivero, F., & Robutti, O. (2002). A cognitive analysis of dragging practises in Cabri environments. *ZDM, 34*(3), 66–72.

Baccaglini-Frank, A., Di Martino, P., & Sinclair, N. (2018). Elementary school teachers' implementation of dynamic geometry using model lesson videos. In E. Bergqvist, M. Österholm, C. Granberg, & L. Sumpter (Eds.), *Proceedings of the 42nd conference of the international group for the psychology of mathematics education* (Vol. 2, pp. 99–106). Umeå, Sweden: PME.

Barad, K. (2007). *Meeting the universe Halfway: Quantum physics and the entanglement of matter and meaning*. Durham, NC: Duke University Press.

Barrett, J. E., & Battista, M. (2011). A case study of different learning trajectories for length measurement. In J. Confrey, A. Maloney, & K. Nguyen (Eds.), *Learning over time: Learning trajectories in mathematics education*. Raleigh, NC: Information Age Publishers.

Bartolini Bussi, M. G., & Mariotti, M. A. (2008). Semiotic mediation in the mathematics classroom: Artefacts and signs after a Vygotskian perspective. In L. English, M. Bartolini Bussi, G. Jones, R. Lesh, & D. Tirosh (Eds.), *Handbook of international research in mathematics education* (pp. 720–749., 2nd éd). Mahwah, NJ: Erlbaum.

Bartolini-Bussi, M., & Boni, M. (2003). Instruments for semiotic mediation in primary school classrooms. *For the Learning of Mathematics, 23*(2), 12–19.

Bateson, G. (1972). *Steps to an ecology of mind* (p. 2000). Chicago, IL: University of Chicago Press.

Battista, M. T. (2007). The development of geometric and spatial thinking. In F. Lester (Ed.), *Second handbook of research on mathematics teaching and learning* (pp. 843–908). Reston, VA: National Council of Teachers of Mathematics.

Châtelet, G. (2000/1993). *Les enjeux du mobile*. Paris: Seuil [English translation by R. Shore & M. Zagha: *Figuring space: Philosophy, mathematics, and physics*. Dordrecht: Kluwer, 2000].

Coles, A. (2014). Transitional devices. *For the Learning of Mathematics, 34*(2), 24–30.

Coles, A., & Sinclair, N. (2017). Re-thinking place value: From metaphor to metonym. *For the Learning of Mathematics, 37*(1), 3–8.

Confrey, J. (1994). Splitting, similarity, and the rate of change: A new approach to multiplication and exponential functions. In G. Harel & J. Confrey (Eds.), *The development of multiplicative reasoning in the learning of mathematics* (pp. 293–332). Albany, NY: State University of New York Press.

Daro, P., Mosher, P., & Corcoran, T. (2011). *Learning trajectories in mathematics: A foundation for standards, curriculum, assessment, and instruction*. Consortium for Policy Research in Education. Available: www.cpre.org.

Davis, B., & Renert, M. (2014). *The math teachers know: Profound understanding of emergent mathematics*. New York, NY: Routledge.

de Freitas, E., & Sinclair, N. (2014). *Mathematics and the body: Material entanglements in the mathematics classroom*. New York, NY: Cambridge University Press.

de Freitas, E., & Sinclair, N. (2017). Concepts as generative devices. In E. de Freitas, N. Sinclair, & A. Coles (Eds.), *What is a mathematical concept?* New York, NY: Cambridge University Press.

Ingold, T. (2007). *Lines: A brief history*. Abingdon, UK: Routledge.

Jackiw, N., & Sinclair, N. (2014), *TouchCounts* (iPad App), Tangible Mathematics Group, SFU. https://itunes.apple.com/ca/app/touchcounts/id897302197?mt=8

Laborde, C. (2001). Integration of technology in the design of geometry tasks with Cabri-geometry. *International Journal of Computers for Mathematical Learning, 6*, 283–317.

Lakoff, G., & Núñez, R. (2000). *Where mathematics comes from: How the embodied mind brings mathematics into being*. New York, UK: Basic Books.

Mishra, P., & Koehler, M. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108*(6), 1017–1054.

Ng, O., & Sinclair, N. (2015). Young children reasoning about symmetry in a dynamic geometry environment. *ZDM Mathematics Education, 47*(3), 421–434.

Ng, O., Sinclair, N., & Davis, B. (2018). Drawing off the page: How new 3D technologies provide insight into cognitive and pedagogical assumptions about mathematics. *The Mathematics Enthusiast, 15*(3), 563–578.

Piaget, J. (1954). *The construction of reality in the child*. (M. Cook, trans.). New York: Basic Books.

Roth, W.-M. (2008). Where are the cultural-historical critiques of "back to the basics"? *Mind, Culture, and Activity, 15*, 269–278.

Rotman, B. (2003). Will the digital computer transform classical mathematics? *Philosophical Transactions of the Royal Society of London, A361*, 1675–1690.

Rotman, B. (2008). *Becoming beside ourselves: The alphabet, ghosts, and distributed human beings*. Durham, NC: Duke University Press.

Ruthven, K. (2014). Frameworks for analysing the expertise that underpins successful integration of digital technologies into everyday teaching practices. In A. Clark-Wilson, O. Robutti, & N. Sinclair (Eds.), *The mathematics teacher in the digital age* (pp. 373–393). New York, NY: Springer.

Ruthven, K., Hennessy, S., & Deaney, R. (2008). Constructions of dynamic geometry: A study of the interpretative flexibility of educational software in classroom practice. *Computers and Education, 51*(1), 297–317.

Star, S., & Griesemer, J. (1989). Instructional ecology, 'translations' and boundary objects: Amateurs and professional in Berkley's museum of vertebrate zoology, 1907–1939. *Social Studies of Science, 19*, 387–420.

Tahta, D. (1998). Counting counts. *Mathematics Teaching, 163*, 4–11.

Wilensky, U. (1991). Abstract meditations on the concrete and concrete implications for mathematics education. In I. Harel & S. Papert (Eds.), *Constructionism* (pp. 193–204). Norwood, NJ: Ablex Publishing Corporation.

Nathalie Sinclair is the Canada Research Chair in Tangible Mathematics Learning at Simon Fraser University and a Professor in the Faculty of Education. She is the founding and current editor of Digital Experiences in Mathematics Education and has authored several books including Mathematics and the Body: Material Entanglements in the Classroom, as well as over 70 journal articles. Her primary areas of research include the role of digital technologies in mathematics education, the teaching and learning of geometry and the nature of mathematical embodiment.

Part III

Teacher Professional Development in the Era of Change

A Sense of Community in a Professional Learning Community of Chemistry Teachers: A Study of an Online Platform for Group Communication

Ruth Waldman and Ron Blonder

Abbreviations

CF	Community facilitator
CtH	Close to home
DE	Discourse episode
LT	Leading teacher
PLC	Professional learning community
SoC	Sense of community

1 Introduction

1.1 *The Context of the Study*

Although there are many different perceptions of the term "teachers' professional learning community" (PLC) (Grossman, Wineburg, & Woolworth, 2001; Lave & Wenger, 1991; Shulman & Sherin, 2004), there is generally a consensus regarding several aspects. Teachers' PLC can be defined as a group of teachers who systematically examine their knowledge and practice in order to improve their teaching. In teachers' PLC the learners are the teachers themselves. Research shows that the PLC should provide an environment for long-term collaboration with colleagues, focusing on teaching content and issues related to the day-to-day practice of teaching (Cochran-Smith & Lytle, 1999; Darling-Hammond & Sykes, 1999).

R. Waldman · R. Blonder (✉)
Department of Science Teaching, Weizmann Institute of Science, Rehovot, Israel
e-mail: Ron.blonder@weizmann.ac.il

Y. Ben-David Kolikant et al. (eds.), *STEM Teachers and Teaching in the Digital Era*, https://doi.org/10.1007/978-3-030-29396-3_7

In a teachers' PLC the teachers themselves share their ideas; they are therefore the recipients and the providers of the knowledge. Such a model promotes control and agency of the teachers over their learning process, and obligates them to be more involved in various activities important for their professional growth, including self-reflection (Mezirow, 1997). PLCs create opportunities for teachers to support each other's professional development, strengthen their feelings of self-efficacy, and their belief in their competence to promote their students' achievements and success (Tschannen-Moran, 2014). Since most high schools in Israel have only one or two chemistry teachers, it is critical to establish a PLC of chemistry teachers to support their professional development. The same occurs in many schools around the world, especially in rural communities (Salazar, Aguirre-Muñoz, Fox, & Nuanez-Lucas, 2010).

In Israel we established a network of chemistry teachers' PLC. The teachers' PLC is used for supporting the PD of chemistry teachers. In these PLCs, chemistry teachers meet face-to-face on a regular basis and engage in three main activities:

1. Building the community: During the face-to-face sessions, emphasis is given to building a community of teachers, beginning with exercises for "breaking the ice", followed by exercises to deepen one's acquaintance with others, set norms and vision, as well as build mutual trust and collaboration.
2. Focusing on student learning: A diagnostic investigation of students' views regarding chemistry as well as the development and implementation of a program designed to prevent some of the misconceptions identified in the first stage, and an evaluation of the new program.
3. Subjects unique to chemistry teaching, such as conducting lab experiments, inclusion of special technologies, and addressing specific difficulties encountered in studying chemistry.

In order to have disciplinary teachers' PLCs, a long-term effort has been made in Israel to support the development of leading teachers (LT) in different scientific disciplines (Fincher, Dziallas, Brandes, Kolikant, & Shapiro, 2016; Hofstein, Carmi, & Ben-Zvi, 2003). In this chapter, we studied the PLC of leading chemistry teachers in Israel. This PLC is part of the chemistry teachers' PLC network that operates as follows: The community of leading teachers (LTs) meets every other week at the Weizmann Institute of Science and during the other week the LTs, in pairs, facilitate the PLC of chemistry teachers, which meet Close to Home (CtH) in different regions throughout Israel. The CtH PLC has a nation-wide community meeting every other Tuesday. The PLC of the chemistry LT provides the LT with a model of how to lead the chemistry PLC CtH. In addition to the actual meetings, the LT PLC has a WhatsApp group (an online communication platform that will be explained later) for the LT and facilitators with whom they continue to discuss different aspects related to chemistry teachers' PLC. In this study we present the results from an analysis of the discourse of the LT via an online platform during its 2 years of activity (2015–2017) and discuss its influence on the sense of community in the PLC.

1.2 The Importance of the Community for Teachers' Professional Development

In their sociocultural theory, Lave and Wenger (1991) asserted that people learn by engaging in a community by contributing to its practices. The participation, reflection, and collaboration are supported, legitimated, and nurtured within a community or culture that values such experiences; it creates many opportunities for these practices to occur and be successfully accomplished and with pleasure (Shulman, 1997). However, working and learning in a community is not based only on socio-cognitive aspects – it also includes the affective-social sides of learning. Learning in a community setting could entail high levels of risk and unpredictability for the participants, since they expose their weaknesses when they seek help from the other teachers in the community. Therefore, teachers require a community culture that supports, scaffolds, and rewards this risk-taking. Tschannen-Moran and Gareis (2015) described trust as a key ingredient for PLCs to succeed, and pointed out that when teachers feel trust, as part of the community, they will have enough confidence to venture out of their comfort zone and take risks, experience new practices, share their failures, and thereby develop and grow. Moreover, Leana (2011) claims that when the relationships among teachers in a school are characterized by high trust and frequent interaction, then student achievement scores improve.

Trust between community peers is one of the most studied social aspects that influences community participation (Macià & García, 2016); however, there are other important affective-social aspects. These aspects in the community are included in the construct "sense of the community" (SoC) (McMillan & Chavis, 1986). SoC in a group practicing together creates the social fabric for learning. A community with a strong SoC involves layers of personal and professional interactions, and encourages trust and willingness to experiment together (Aurami, 2017).

Our research focuses on better understanding the notion of SoC as it is manifested in chemistry teachers' PLC. For this purpose, we chose the theoretical framework of McMillan and Chavis (1986), which we will explain next.

1.3 Sense of Community

SoC was defined by McMillan and Chavis (1986) as "a feeling that members have of belonging, a feeling that members matter to one another and to the group, and a shared faith that members' needs will be met through their commitment to be together." (p. 9). Four elements are essential for building and maintaining SoC (McMillan & Chavis, 1986). An elaborate description of the four elements is presented in the Results section.

1. *Membership:* The members have a feeling of belonging to a group or of sharing with others a sense of personal relatedness. Important for membership is having a distinction from non-members.
2. *Influence:* When members contribute to the group, then they have a sense of importance. When the community contributes to its members, it becomes important to them. This is a reciprocal direction of influence that contributes to this element.
3. *Fulfillment of needs and reinforcement:* A strong community is able to accommodate people so that people meet each other's needs as well as their own. Reinforcement is one of these needs.
4. *Emotional connection:* The commitment and belief that members have shared and will share history, common places, their time together, and similar experiences.

In this chapter we study a community of teachers who communicate via an online platform called WhatsApp. We therefore will provide a literature review of communities in the online environment, which will be followed by a presentation of the WhatsApp online environment.

1.4 SoC in Online Communities

When students in on-line learning communities have SoC, they feel involved in the learning community, and have an opportunity to develop relationships with other members of the community. Studies on SoC regarding online learning have emphasized the importance of SoC in reducing dropout rates, elevating the students' level of satisfaction, and their likelihood of persisting in a program (Moore, 2014; Tinto, 1993). Furthermore, studies of online environments provide evidence that one can create a SoC and sustain strong ties through digital media (Baym, 1995; Rheingold, 1993; Rovai, 2002). Social factors are important in the development and maintenance of communities. They facilitate the maturing of the community, knowledge sharing, longer engagements and community outcome expectations (Macià & García, 2016). In addition, Grossman et al. (2001) claimed that holding real-life meetings in PLCs are not enough to ensure the development of a sense of community. It has also been shown that participation in face-to-face meetings does not always involve cooperation between community members, especially in those cases that require greater commitment from participants, e.g., collaborative creation of artefacts (Coutinho & Lisbôa, 2013).

In the current study we examined the support and the added value of an online platform, WhatsApp, to the SoC of a PLC of leading chemistry teachers.

1.5 WhatsApp Application Groups

The smartphone application, WhatsApp, has been available since 2010, and was developed as a replacement of SMS text messaging; it is free of charge and ad-free. Currently it operates on almost all types of smartphones, and it is also accessible from desktop computers, and includes the ability to send and receive, in addition to text messages, all types of attachments, such as pictures, video clips, audio files, and documents (O'Hara, Massimi, Harper, Rubens, & Morris, 2014).

Being simple to operate and free of charge, the app has gained widespread popularity among people of all ages and backgrounds and has become one of the most heavily used applications for online immediate communication (Seufert, Hoßfeld, Schwind, Burger, & Tran-Gia, 2016). As of February 2016, WhatsApp has over 1 billion users globally (Stat, 2016). A recent study among Israelis found that WhatsApp was used by 67% of the respondents and 52% reported that they send messages in WhatsApp groups on a daily basis (Avidar, Ariel, Malka, & Levy, 2013).

One of its main positive characteristics is its capacity to carry out and enhance group communication; thus, it can be viewed as a social media network that allows people to access a great deal of information rapidly. All of the participants in the group enjoy equal rights and it knits together the community of friends, family, or teachers and creates a sense of community (Bouhnik & Deshen, 2014). In general, social media is a broad categorical term for technologies that facilitate user sharing, content creation, and information exchange within online communities or networks. Specifically, social media platforms can be defined as technologies "that allow the creation and exchange of user-generated content," (Kaplan & Haenlein, 2010, p. 61).

According to Church and Oliveira (2013), there are three main advantages of using the WhatsApp application: the economic advantage (it is free), the immediate response of the group members, and the enhancement of the SoC of the group members. Other applications share these advantages and are popular in different countries. Moreover, they could be used for the same purpose (e.g., WeChat in China).

The PLC of the leading chemistry teachers opened a WhatsApp group that is being used for different purposes (e.g., social chatting, announcements, links to relevant sites, and questions in chemistry (Rap & Blonder, 2016)). Overall, research on the SoC in PLCs that hold both real-life meetings and online interactions is sparse. Here, we will address this issue by analyzing how the interactions in the WhatsApp group of a PLC support the development of a SoC.

2 Research Question

How, if at all, does the discourse in the WhatsApp group of the leading chemistry teachers' PLC support the building of SoC? (if so, how?)

3 Methodology

This is a qualitative study that utilized an inductive approach in which data were analyzed using a modified Grounded Theory approach (Strauss & Corbin, 1998).

3.1 Participants

The study's participants included a community of 14 leading teachers (LTs) and 5 community facilitators (CFs). The LTs were in-service chemistry teachers that were selected by a chemistry supervisor (the person who is in charge of the chemistry discipline at the Ministry of Education) to lead chemistry PLCs. As described before, The LTs lead chemistry teachers' PLC that operate in different regions in Israel and provide a nation-wide professional development framework for the chemistry teachers in Israel. The LTs and the CFs meet every other week at the Weizmann Institute of Science to build together the activities they conduct in the PLC that they lead. Between the face-to-face meetings at Weizmann, they use a WhatsApp group that provides an online communication platform. In this study, the written discourse via the online platform throughout two academic years was analyzed. The authors are also part of the community being studied; the first author is one of the leading teachers and the second author is one of the community facilitators.

3.2 Data Analysis

The data in the WhatsApp group were divided into Discourse Episodes (DEs) that were defined as follows: a discourse event that was opened in the WhatsApp group and deals with a certain topic. Each DE includes all the posts in the discourse event until a new DE is opened. During the two academic years of research (2015–2017), 6100 posts were written. These posts were gathered into 300 DEs. The names of the participants were coded before the analysis by the researchers, and pseudonyms were used to maintain the participants' privacy.

For each DE the initial goal for opening the discourse was identified using a bottom-up approach: First, each DE was coded to sub-categories according to its identified goal (namely, why the DE was initiated). These initial codes were classified into general categories of DE goals (Miles, Huberman, & Saldana, 2013). For example, the DE goal of "Seeking help, clarifications, and consulting" included the initial codes of help and questions about the chemistry content knowledge, organizational questions, asking for teaching materials, help and questions about chemistry teaching, and help and questions about leading the regional communities of chemistry teachers, which are called the Close to Home (CtH) PLC.

The DEs were analyzed according to the SoC theory of McMillan and Chavis (1986). Elements composing the SoC (the elements are presented in the Introduction, and further explained in the Results section) were identified by the first author in the DE, and the categorization of the DEs was validated by the second author. Cases of disagreement were discussed until a consensus was reached. The categorization was conducted in order to examine how the SoC of the members in the WhatsApp group is supported in the group according to the theoretical framework of McMillan and Chavis (1986).

In addition to the qualitative analysis, a quantitative method was used for obtaining descriptive quantitative information about the WhatsApp discourse as a whole. The 2-year-long discourse in the WhatsApp group was analyzed in the WhatsApp analyzer application for different descriptive statistical analyses (Seufert, Schwind, Hoßfeld, & Tran-Gia, 2015).

4 Results

4.1 *The Goals for Beginning a Conversation*

In order to better understand the discourse in the WhatsApp group, the discourse that took place over the first 2 years of activity was classified according to the goal of beginning each DE. One of the characteristics of the conversations in the WhatsApp group is their goal, since each conversation is initiated by one of the participants with a certain goal in mind. In reviewing the DE in the group, we identified the following goals: seeking help, clarifications and consulting; sharing; reinforcement and recognition; socializing; general information and messages. The classification of the DE according to their goals is shown in Table 1. Aiming to better understand the SoC of the leading chemistry teachers' PLC, we performed a theoretical match between the various conversation goals and the elements of SoC (Table 1). Most of the discourse in the WhatsApp group is related to the elements that make up the SoC of the community members, as will be elaborated. In the next section, an analysis of the DEs according to the each of the SoC elements is presented.

4.2 *Membership*

Membership in SoC theory includes the feeling of belonging, which is composed of sub-elements, as proposed by McMillan and Chavis (1986):

1. Boundaries – barriers designating who belongs and who does not, providing the structure and security needed to protect group intimacy, and having a common symbol system denoting membership.

Table 1 The goals of the DE in the WhatsApp group during the academic years 2015–6 and 2016–7, and their connection to the elements of SoC theory

DE goal	Goal sub-categories	Elements of SoC reflected in the goals	Number of conversations 2015–6 (%)	Number of conversations 2016–7 (%)
Sharing	Leaders' meetings Meetings of CtH and symposia Activities from the classroom Teaching materials in chemistry Interesting websites, links, and animations	Membership Influence Fulfilment of needs and reinforcement Emotional connection	56 (38%)	110 (40%)
Seeking help, clarifications, and consulting	Administrative issues Chemistry teaching issues Chemistry issues	Fulfilment of needs and reinforcement Influence	52 (35%)	85 (31%)
Social	Happy birthday greetings Greetings for holidays Greetings for the birth of a child Condolences Wishes for success Addressing missing colleagues	Membership Fulfilment of needs and reinforcement Emotional connection Influence	26 (17%)	41 (15%)
Reinforcement and recognition	Following the organizing of symposia Following attendance at CtH community meetings After receiving a prize	Fulfilment of needs and reinforcement Influence	9 (6%)	11 (4%)
General information regarding technical issues	Location of meeting Things to bring Forms to be filled out Management of CtH community courses Coordinating a meeting	Not connected to SoC	6 (4%)	26 (10%)
Total			149 (100%)	273 (100%)

2. Emotional safety – being able to speak honestly, feeling safe to be vulnerable.
3. A sense of belonging and identification – involves the feeling, belief, and expectation that one fits in the group and has a place there, a feeling of acceptance by the group. The role of identification must be emphasized here. It may be represented in the reciprocal statements, “It is my group” and “I am part of the group.”
4. Personal investment – working for membership will provide a feeling that one has earned a place in the group. And, as a consequence of this personal investment, membership will be more meaningful and valuable.

Here we examine these sub-elements in the WhatsApp discourse.

4.2.1 Boundaries

The WhatsApp group has distinct boundaries, since it belongs exclusively to the leading community members, who remained unchanged throughout the academic year. The WhatsApp group has an icon (usually a group photo of all its members) that also reflects these boundaries.

4.2.2 Emotional Safety

Over the course of the two academic years studied, 31–35% of the conversations were opened for help, clarifications, and consulting. Asking for help puts the seeker at a vulnerable position, since he sometimes reveals his shortcomings in knowledge of various professional subjects or his inability to handle administrative issues. Throughout the 2-year period, we examined the variation in the number of queries for help regarding professional issues and the members who requested it: whether were they from the community facilitators (CF) or from leading teachers (LTs). The results of this analysis are shown in Table 2.

The first request for help on a professional subject was posted by one of the community facilitators, Mira (CF), 1 month after the WhatsApp group had been opened. On November 2, 2015 she asked: “Does anybody have a good unseen[1] about the anomaly of water?” In her request for help, she showed respect for other members by assuming that they might provide her with a useful answer, while at the same time, the fact that she lacked knowledge, could have opened her up to criticism by the rest of the group (they could think - “How come a member of the community facilitators doesn’t have a good unseen for a basic subject such as water?”). The next professional help request event occurred 2 months afterwards.

In the second semester, the increased number of questions may indicate a higher level of emotional safety among members. A member of the community, Erez (LT), stated at the end of the 2016 matriculation exam, “I have a dilemma about question 2 in “energy”: the wording is very unclear.” Presenting the dilemma could put the

Table 2 The number of requests for help and advice regarding professional issues during the 2-year period, the distribution of the requests among the community facilitators and the leading teachers’ group, and the percentage of requests from the total DE

Semester	Requests by leading teachers	Requests by community facilitators	Total requests	Total requests from the total DE (%)
1	4	1	5	7.6
2	10	1	11	13
3	4	2	6	3.5
4	16	1	17	10

---

[1] An unseen is short scientific articles, which are adapted. The students need to read the article and answer questions that are based on understanding the scientific content.

member in a vulnerable position, since the matriculation exam is checked by many professionals, so that there should be no unclear questions. Therefore, when he wrote that the question is not clear, he may have had a lack of understanding of the issue at hand, i.e., a lack of knowledge of chemistry at the high-school level. This situation may expose him to criticism from members of the community. However, the member felt comfortable enough to ask the question and took advantage of the trust that had developed during the year. Indeed, the answers that he received were empathetic, "It was not clear to me, either," wrote Gili (LT), "I think the correct answer is …," wrote Mili (LT), which did not create a sense of discomfort. An increase from the first to the second semester was followed by a decrease in the third semester, and again an increase during the fourth semester. Note that in the third semester there was a change in the composition of the group members, since some of the LTs left, and new members joined; consequently, at the beginning of the second academic year, the members' emotional security had to be rebuilt. One can see that most of the questions are being asked by the LTs, namely, the LTs are leading the discourse and feel confident to ask for help. Note that in all periods of activity of the community's WhatsApp group, the number of requests for public assistance was not high: out of hundreds of discourse events, there were only 39 requests, all of which received very professional and empathetic responses.

4.2.3 Personal Investment

Much activity occurred in the WhatsApp group throughout the week, with the hours of operation from 6 am to midnight. Figure 1 shows the distribution of messages written in the WhatsApp group of the leading community during the second semester, according to the days of the week. The peak activity takes place on Tuesdays,

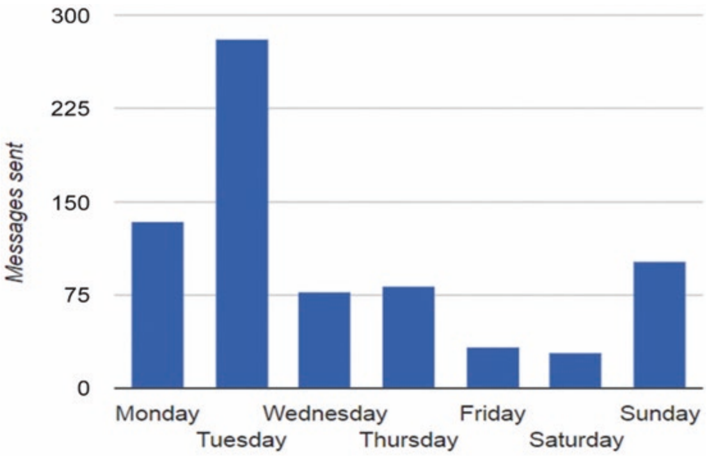


Fig. 1 The number of messages written in the WhatsApp group of the leading community in the second semester, according to the days of the week

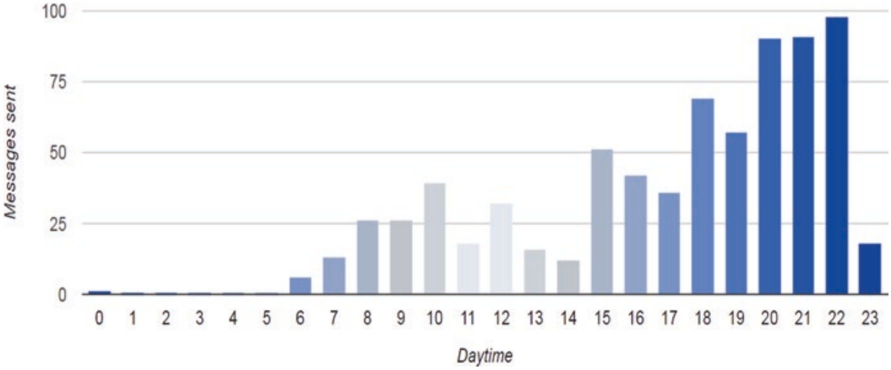


Fig. 2 The number of messages written in the WhatsApp group of the leading community in the second semester, according to the hours of the day

during the face-to-face meetings of the community leaders. Activity is also high on Mondays, when discussions are held in preparing for the Tuesday meetings.

Figure 2 shows that the activity occurs throughout the day, from 6 am to 11 pm, indicating that the group members are continuously active, and have invested in the group activities. The more an individual invests in a group, the more he feels that he has earned the right to be a member, so his membership will be more significant and will have greater value.

4.2.4 A Sense of Belonging and Identification

These feelings were expressed in many messages written by members of the community on WhatsApp. Members of the community wrote explicitly: "Proud to belong," "I am happy that we are marching together" (following the birthday greetings of a leading team member Dalit (CF)), "It's fun to feel part of such a significant community" (Ben (LT), following a meeting on Hanukkah). A very tangible and strong expression of the sense of belonging can be found in a set of two pictures shared by two community members, who dressed up for Purim as a community of chemistry teachers, with symbols of the community, as shown in Fig. 3.

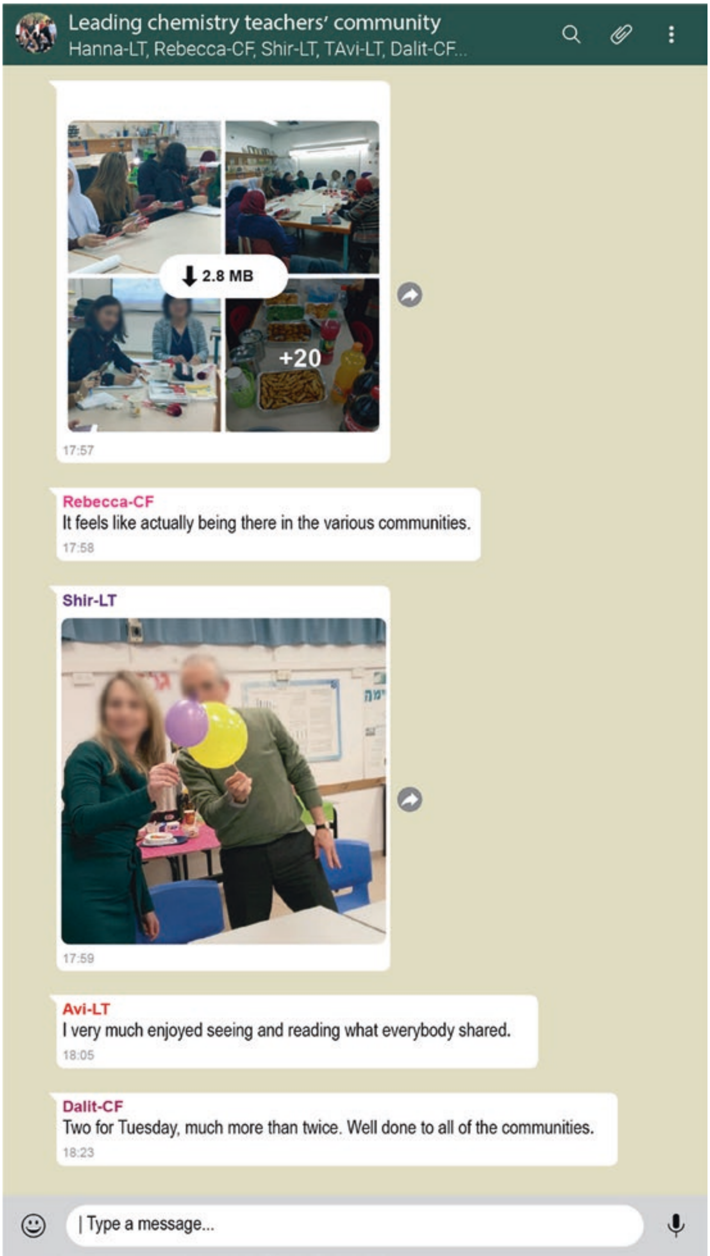
Immediately after uploading the pictures, they received enthusiastic responses from eight members of the community, indicating that the community is part of their identity and that they are part of the community.

A sense of belonging is also built through sharing. Sharing constituted the goal of many dialogue events (about 40% of the events in the discourse, see Table 1). The exchanges mainly concerned chemistry teaching materials, which included Web sites of interest, links, animations, activities from the class, and information about leaders' meetings, important events of the community, and meetings held simultaneously throughout the country in various communities.

Fig. 3 Two community members dressed up as the communities they lead. In dressing up, they identify with their community

On Tuesdays, when nation-wide CtH communities held their meetings, all LT send dozens of posts and photos gathered from all the CtH communities. The intensive work that is expressed in the photos led to enthusiastic responses from all the PLC members, as can be seen in Fig. 4. These discourses create a strong sense of presence and belonging to the nation-wide activity for all the PLC members, even though they are not physically together. As one CF member wrote: "It feels like actually being there in the various communities" (Rebecca (CF), Fig. 4). She expresses the feeling created by the platform, of being present in various places, thus creating a feeling of belonging.

In order to demonstrate how the WhatsApp group influenced the sense of belonging and group identity, we present a vignette that took place on the day of the CtH meetings. In one of the CtH communities, owing to a coordination error, the meeting did not take place, whereas all the other communities held meetings. One leader of this community saw all the photos posted by the other leaders from their meetings, which made her feel very bad about the situation, so in a private WhatsApp message to the second author, she wrote: "We were surprised to discover from the WhatsApp correspondence that everyone had a meeting; however, we didn't know that there was supposed to be one today. I really feel we failed, we won't be able to



17:57

Rebecca-CF
It feels like actually being there in the various communities.
17:58

Shir-LT
17:59

Avi-LT
I very much enjoyed seeing and reading what everybody shared.
18:05

Dalit-CF
Two for Tuesday, much more than twice. Well done to all of the communities.
18:23

Fig. 4 Illustration of a WhatsApp conversation on a nation-wide community meeting day catch up with the rest, we might as well leave." She ended the conversation by saying: "Good night, it's not for us." We could see how the intense activity of the WhatsApp group, to which she did not feel that she belonged that day, has had a negative impact on her sense of belonging to the community. This event shows how the activity in the group can lead to changes in the sense of belonging of the group members, and influence the SoC in the leading community.

4.3 Influence

The second element we examined in the WhatsApp group is the "influence", which is based on the following sub-elements (McMillan & Chavis, 1986):

1. Members are more attracted to a community when they feel that they can influence and improve it.
2. The community imposes norms in order to maintain cohesiveness, and the members adapt to the community norms in order to gain recognition from the other members and attain a feeling of membership.
3. The influence of a member on the community and the influence of the community on a member operate concurrently, and one might expect to see the force of both operating simultaneously in a tightly knit community.

The community establishes common norms in the WhatsApp discourse, which support sharing, respect, acceptance, listening, mutual help, and more. The community determines goals for integrating new chemistry activities into the classroom and within the community, and for integrating a learner-centered teaching approach. Thus, the community influences the members, while at the same time, the members influence the community; the impact is bi-directional, mutual, and concurrent. The effect is evident in the WhatsApp group in almost every DE. In each episode there are from 2 to 20 participants. Many DEs include numerous messages, so their influence and time span are large. There are no messages that remain without comments. The influence of the messages is manifested by the members reading the post and reacting. The more reactions there are, the stronger the impact.

In face-to-face meetings the main impact is from the CF. The CF determines the agenda, the activities, and guides most of the discussions. The influence of the LTs is secondary. On the other hand, in the WhatsApp discourse, one of the prominent "players", who determines the agenda of the community, are the LTs. The top five members who wrote the highest number of messages included two CFs (out of 5) and three LTs (out of 14). In the second semester, the largest number of posts were written by LTs, rather than CFs. Bearing in mind that by posting messages, members can influence their colleagues in the PLC, the composition of the members who wrote more messages, and therefore, had more influence, varied between the two semesters of the first year of activity.

Next, we will demonstrate the element of influence, by showing an example of a DE initiated by community member Ben (LT) on Oct. 21, 2015. The DE began at

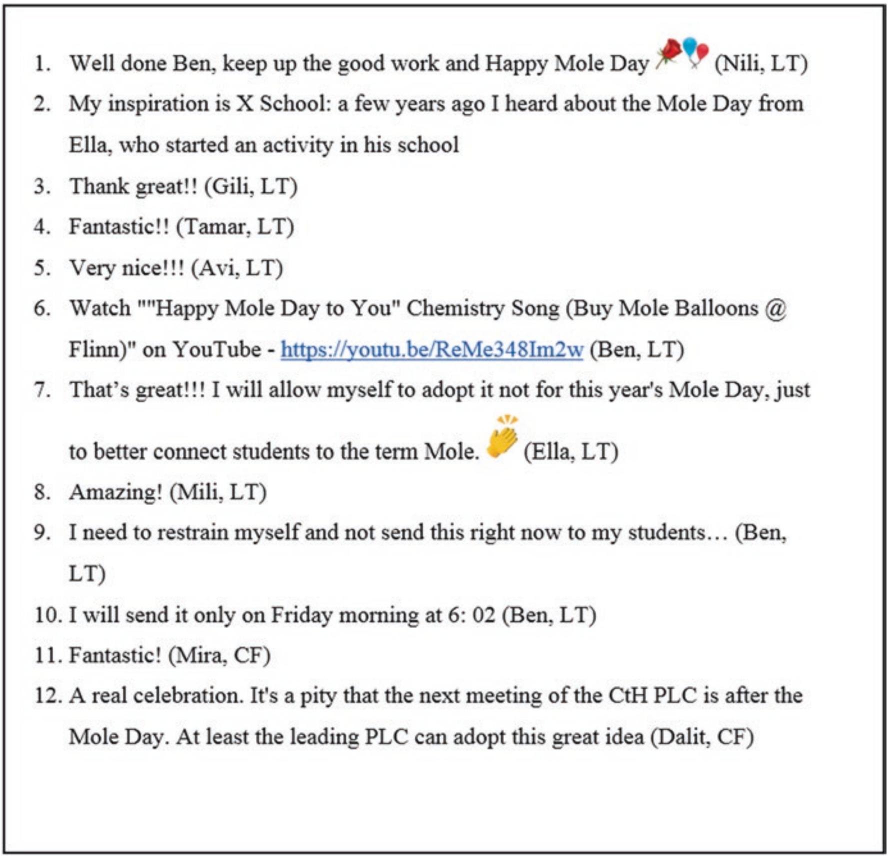
Fig. 5 Images from an activity conducted by Ben (LT) with his students in preparation for Mole Day. (∗An example of a quiz: how many moles of iron are in the jar?)

18:41 when community member Ben (LT) shared his preparations for the “the Mole Day” on Oct. 23rd.[2] The event began with the publication of six posts by Ben (LT), including pictures and short explanations about the preparations he made with his class for Mole Day. Selected pictures that he posted are shown in Fig. 5. The discourse continued as presented in Fig. 6.

The publication of the photos led to enthusiastic responses and reinforcement from all members of the community. As a response, Ben (LT), who published the photos, gave honor and credit to another community member from whom he received the idea. In message number 7, community member Ella (LT) wrote: “I will allow myself to adopt it”. This statement indicated that one member of the community (Ben) influenced the other. Summarizing the discussion for that day, Dalit (CF) suggested: “At least the leading PLC can adopt this great idea” (message 12); this positioned the teacher as a main actor, whose ideas are worth adopting.

---

[2] The chemists celebrate the Mole Day on Oct. 23rd, since the number of particles in a mole is 10^{23}.



1. Well done Ben, keep up the good work and Happy Mole Day 🌹🎈 (Nili, LT)
2. My inspiration is X School: a few years ago I heard about the Mole Day from Ella, who started an activity in his school
3. Thank great!! (Gili, LT)
4. Fantastic!! (Tamar, LT)
5. Very nice!!! (Avi, LT)
6. Watch ""Happy Mole Day to You" Chemistry Song (Buy Mole Balloons @ Flinn)" on YouTube - https://youtu.be/ReMe348Im2w (Ben, LT)
7. That's great!!! I will allow myself to adopt it not for this year's Mole Day, just to better connect students to the term Mole. 👏 (Ella, LT)
8. Amazing! (Mili, LT)
9. I need to restrain myself and not send this right now to my students… (Ben, LT)
10. I will send it only on Friday morning at 6: 02 (Ben, LT)
11. Fantastic! (Mira, CF)
12. A real celebration. It's a pity that the next meeting of the CtH PLC is after the Mole Day. At least the leading PLC can adopt this great idea (Dalit, CF)

Fig. 6 Responses to a post describing the activity of a LT for Mole Day. (Date; Oct. 21, 2015; Time: 15:30–17:35, nine participants, part of a longer discourse)

The discourse continued on Mole Day itself, on Oct. 23, 2015, with Ben (LT) publishing five pictures describing the activity on the day itself, at 10:47. Following, and presumably as a result, another LT (Karin) posted pictures from the Mole Day event at her school. She received reinforcement from the other members, and the CF suggested adopting her ideas as well. The discourse continued until the evening, when the member of the community who opened the conversation posted "the day is over." The conversation caused extensive participation (28 posts) by half of the PLC members.

This activity in the WhatsApp group had additional long-term effects. About a month after this conversation, Karin's idea was adopted at the LT PLC meeting. A year later, the leaders integrated the concept of Mole Day into volunteering activities in the neighborhood and documented the activity on the WhatsApp group.

4.4 Fulfilling Needs and Reinforcement

The third element of SoC to be examined is fulfilling needs and reinforcement, which is composed of the following sub-elements:

1. Communities meet members' needs – a strong community is able to accommodate people so that people meet others' needs as well as their own.
2. Trade – every member is different; therefore, each member contributes something of value to the community, to the benefit of the other members: "I will give them something of value that they don't have and I accept something from them that I don't have."
3. Reinforcement is a strong motivator of behavior; for any group to maintain a positive sense of togetherness, the individual-group association must be rewarding for its members. Strong reinforcement of belonging includes the status, success, and competency of the members.

In this section, we examine the LTs' needs and the ways they are fulfilled via the WhatsApp discourse. About a third of the goals of opening a WhatsApp discourse were for seeking help clarifications and for consulting regarding chemistry, chemistry teaching, and management (see Table 1). Members' needs were fulfilled through their almost immediate interaction with the group, since it took a very short time from the time the question or request for help was raised until a response was received. Community members asked questions regarding an explanation of the results of a chemical experiment, such as "I have a question about the results of the experiment"; they asked questions regarding the curriculum, as in "How should we relate to the microscopic description", "What is the difference between evaporation and boiling?", "Methylamine has high solubility in water, whereas methyl chloride has negligible solubility in water. How can this be explained?" They also raised questions about the technical level: "How do I fill out the report for the district?" Namely, the needs of the LT are reflected in all the different DE goals that are presented in Table 1.

As shown in Table 1, and discussed in Sect. 4.2, one of the most common DE goals was sharing. The widespread sharing also fulfilled the need for building community knowledge, de-privatization of classroom teaching, and for guidance in communities.

In addition to DEs intended for sharing, there were also DEs initiated for social purposes (17–15% first and second year, respectively). These events included the following: greetings for a birthday, for a holiday, the birth of a child, condolences, wishing success and referring to community members who were missing at the meeting. All these fulfilled the need for a sense of belonging and being a significant part of the group.

Another need for the WhatsApp group was reinforcement and recognition. Four to six percent of the DEs were opened with the aim of strengthening and providing recognition for the LTs (see Table 1). Although these percentages seem low, the DEs were long and significant, because they referred to exceptional achievements and received a high number of responses. For example, following a visit to the CtH meeting, a CF, Sandy, noted her feelings about the visit to the community by praising the leadership and the interesting activities she had witnessed:

> A spontaneous decision led to total enjoyment ... I really enjoyed the activities in the community ... The teachers appreciate you very much, and the atmosphere is really good; I was very moved by the teacher who said that she does not usually connect with others, but she decided to join the CtH community, benefits from it, and contributes in return. The feedback was great, and I was happy that all the teachers, without exception, praised the diagnostic tasks.

In addition to DEs that were opened with the aim of recognition and reinforcement, about 30% of the DEs included reinforcement, although they were opened for a different purpose.

4.5 Emotional Connection

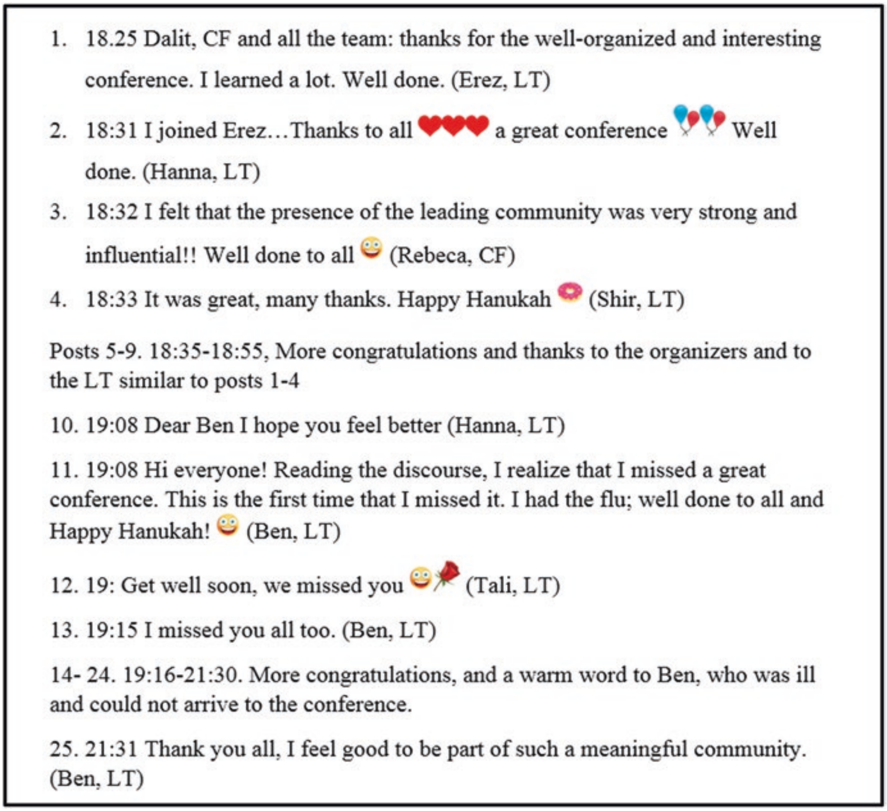
The fourth element of building a SoC is a shared emotional connection in time and space, which is composed of the flowing sub-elements (McMillan & Chavis, 1986):

1. Contact hypothesis: The more people interact, the more likely they are to become closer; members must share time together.
2. The quality of interaction: The more positive the experience and the relationships, the stronger the bond; success facilitates cohesion.
3. Shared significant events: The more important the shared event is to those involved, the greater the community bond; events must have value and closure.
4. Events must honor members.

According to contact theory (McMillan, 1996), the more time that members spend together, the more likely they are to be closer and to connect. Although this is virtual space, WhatsApp allowed group members to have more time together. The intensity in terms of hours and days during which the members connected is reflected in Figs. 1 and 2.

In terms of the quality of the interaction, the nature of the discourse was examined. Mapping the various discourse topics in the group shows that many of the discourse events dealt directly with teaching chemistry and instructing communities of teachers. A discussion on teaching chemistry included aspects of : chemistry teaching, the chemical laboratory, CtH meetings, and LT PLC meetings (Blonder & Waldman, 2019).

Significant joint events, which were successfully completed also contributed to creating an emotional connection. Over the years, the community has conducted or has been responsible for significant events that took place, such as the National Conference of Chemistry Teachers on Hanukkah, 2016. The LTs contributed significantly to the conference, thus enabling a glimpse into the activities of the communities in general. During the conference, photos of the LTs that were posted on the WhatsApp group by other LTs, honor and reflect the sense of shared togetherness.



1. 18.25 Dalit, CF and all the team: thanks for the well-organized and interesting conference. I learned a lot. Well done. (Erez, LT)
2. 18:31 I joined Erez…Thanks to all ❤❤❤ a great conference 🎈🎈🎈 Well done. (Hanna, LT)
3. 18:32 I felt that the presence of the leading community was very strong and influential!! Well done to all 😁 (Rebeca, CF)
4. 18:33 It was great, many thanks. Happy Hanukah 🍩 (Shir, LT)

Posts 5-9. 18:35-18:55, More congratulations and thanks to the organizers and to the LT similar to posts 1-4

10. 19:08 Dear Ben I hope you feel better (Hanna, LT)

11. 19:08 Hi everyone! Reading the discourse, I realize that I missed a great conference. This is the first time that I missed it. I had the flu; well done to all and Happy Hanukah! 😁 (Ben, LT)

12. 19: Get well soon, we missed you 😁🌹 (Tali, LT)

13. 19:15 I missed you all too. (Ben, LT)

14- 24. 19:16-21:30. More congratulations, and a warm word to Ben, who was ill and could not arrive to the conference.

25. 21:31 Thank you all, I feel good to be part of such a meaningful community. (Ben, LT)

Fig. 7 A community discourse following the chemistry teachers' annual conference, Hanukah, 2016. (Date; Dec. 28, 2016; Time: 18:25–21:31, all community members: LT and CF participated. The exact times of publishing the posts were omitted)

The discourse following the chemistry teachers' annual conference, Hanukah, 2016 is shown in Fig. 7.

During the chemistry teachers' annual conference, there were sessions where all the teachers were together (i.e., plenaries), and there were also parallel sessions, preventing the attendees from participating in all the presentations. Each of the LTs contributed to the community by attending a different parallel session, and sending photos to the WhatsApp group. In this way, the contribution of every LT was recorded and appraised by the other members. In addition to this part, which occurred during the conference, the discourse in the WhatsApp continued after the end of the conference. This part included thanks, honors, and reinforcements to the CFs, LTs, and the entire community. Figure 7 shows the contribution of the WhatsApp group to the creation of shared significant events for the LT PLC. This event became part of the shared history of the community, and contributed to strengthening the bond between the members.

In an oral discourse, usually there is not as much reinforcement as is possible to find in a WhatsApp group. A member of the community, Ben (LT), was missing from the chemistry teachers' annual conference. Many members of the community referred to him, so Ben (LT) thanked everyone a number of times and summarized with the following sentence: "I feel good to be part of such a meaningful community". A community member who was not at the conference expressed his emotions that it feels good to belong and to connect with others, thus giving everyone a sense of unity.

5 Discussion

5.1 Mechanism of Influence and Recommendations

Here we present a summary of the results in order to examine the mechanism by which the WhatsApp group supports the elements of the SoC. This part will be combined with our recommendations how to enable and enhance this support.

5.1.1 In Terms of Membership

Community Symbols

The sense of belonging can be identified in, and is enhanced by, the WhatsApp group icon (the symbol of the group), which is a picture of the members of the community. A common symbol serves several important functions in creating and maintaining a sense of the community. Nisbet, Perrin, and Page (1977) stated, "First and foremost of the social bond is the symbolic nature of all true behavior or interaction" (p. 39).

We suggest choosing an initial icon that is meaningful and important for the community members. It can be a group photo of the community members taken in the first face-to-face meeting, or a picture of the subject of the community, such as a molecule for a community of chemistry teachers. The icon can be replaced after a meaningful event by a photo taken at the event, since this act can serve as a closure to the event.

Building Trust

The WhatsApp group has clear boundaries that enable the creation of a "protected space" for members. In order for the space to be protected, it is important to build respectful and inclusive norms. In this way, the WhatsApp group is an intimate and safe space for members to be open and freely express themselves, without fear of criticism or humiliation. The element of emotional safety is evident from the fact that as time went by, the members of the community were progressively less afraid to ask for help, to consult with their peers, and to reveal gaps in their knowledge (Table 2). Booth (2012) found that the facilitators play an important role in cultivating a trusting environment in online learning communities by supporting and encouraging trustworthy behavior.

For building of trust, we recommend that the CFs will set an example by asking questions that expose a lack of professional knowledge, enabling the members to spontaneously reply. When one of the community members asks a question, the CFs should make sure that he gets an adequate, prompt, and respectful reply. In case such a reply is not given, or replies are not respectful enough, the CFs should act behind the scenes (i.e., by means of private messages or a phone call) to correct the situation.

Investment of Time

The group members used WhatsApp extensively, for days and for many hours of the day (Figs. 1 and 2). The exchanges in the WhatsApp group were not limited like in the face-to-face meetings, which lasted for 4 h every 2 weeks. The WhatsApp environment therefore allows members to invest time in the group between the meetings. The investment of time in the group and the contribution of each member give an individual the feeling that he has earned a place in the group, and therefore, his membership will have more meaning and value.

We recommend encouraging members to invest time in the group in meaningful ways such as in sharing, as well as providing feedback and response; this will give them a feeling that they belong.

Tuesday Event – Shared Virtual Event – A Sense of Presence

Every other week, when nation-wide CtH communities held their meetings, we witnessed the norm of sharing photos accompanied by a few verbal explanations about the related meeting (Fig. 4). This discourse not only reflected what was happening in the communities, it also created a virtual event with a strong sense of presence and belonging to the nation-wide activity for all the PLC members even though they were not altogether.

Karapanos, Teixeira, and Gouveia (2016), in their interviews on satisfying experiences with WhatsApp, reported that in WhatsApp's restricted environment the users experienced a very high sense of presence in communicating with others. This sense of presence of all participants enables intimate conversations that support a sense of belonging to the group.

For sharing encouragement, we recommend that the CFs establish a norm of publicizing the teaching in the CtH and the classroom through sharing of pictures or inviting members to do so immediately following the event.

During the LT PLC Meetings

During the LT PLC meetings, two factors in the WhatsApp group contributed to building a sense of belonging: one was sharing pictures from meetings, which was done by the CF, during and after the meeting. This also supported the sense of belonging to a community, since it reflected the experience of a joint event. The second is a reference to members who were absent from the meetings. This enabled a member who missed a meeting to still feel that he belongs to the community even when not being physically present.

We suggest that the CFs initiate a norm whereby the group addresses members who were missing from an event, by posting appropriate messages in the group, thus augmenting the feeling of belonging.

5.2 In Terms of Influence

The element of influence can be seen in the many posts by members, all of whom received responses from many members. Responses ranged from one-liners to those spanning a large number of lines, as illustrated by the representative DEs presented.

The WhatsApp discourse reveals the influence of members on the community, as shown in the Mole Day event (Figs. 4 and 5), where a long-term influence that spanned over months and even years was noted. In addition, all members of the community had an equal chance to exert their influence, regardless of their role (CF or LT). Furthermore, WhatsApp enables all members of the community to express their opinion, without hierarchy. Each post has an impact, and the effect can be extensive when there are many reactions to the post, not just short reactions (e.g., an emoji or a like) but instead, extensive verbal responses.

For increasing the feeling of influence, we recommend that the CFs make sure that each post receives reactions and, if possible, adopting members' suggestions addressed to the LT PLC.

WhatsApp enables the building of community norms. The members "see" the responses of the leading team and the rest of the community, and the spontaneous responses create norms of behavior. This includes, for example, norms of sharing, exposure of teaching in the classroom and in the community, as well as norms of acceptance and encouragement. The deliberate personal example of the CF is a mechanism used to create those norms previously mentioned.

5.3 In Terms of Fulfillment of Needs and Reinforcement

The element of fulfillment of needs and reinforcement was expressed in the goals for which the DEs were opened. About a third of the goals of opening a WhatsApp discourse dealt with asking for help, clarification, and consultation regarding chemistry, chemistry teaching, and management (see Table 1). In all cases, the members received satisfactory answers from the group. The group also met social needs and included personal attention to social events, such as birthdays, holidays, joyous and sad events (15–17% of the events). This fulfilled the need for a social connection beyond the professional aspect, which is essential for knowledge development in an online community (Garrison & Arbaugh, 2007; Rap & Blonder, 2016).

Regarding the professional aspects, when difficulties, questions, or the need to consult arose, the LTs had whom to ask. Through one post, the question that bothered the LT was simultaneously passed on to all members of the group. We found that the responses were received during all waking hours (see Table 2). As was indicated in the Introduction, most members of the community and many of the chemistry teachers in Israel are the only chemistry teacher in their school or have only one other colleague. When they encounter a question in the content or pedagogical field, they have no one with whom to consult. The WhatsApp serves as an important tool for receiving professional guidance from others. Thus, the WhatsApp group met their needs. Almost 40% of the goals of the DE were related to sharing. Sharing is a community need and WhatsApp is a convenient and fast platform for sharing. All members share their ideas and expertise, and benefit from information shared by their peers.

One of the strengths of the WhatsApp group lies in fulfilling the need for reinforcement and recognition bestowed on the members. The LTs tried innovative teaching methods to which they were exposed in the LT PLC meetings, thought of pedagogical responses to difficulties encountered, and planned the guidance sessions for the CtH community. All these activities and trials were shared in the WhatsApp group and received reinforcement and recognition by the PLC members and by the CF. Such reinforcement seldom occurs in face-to-face meetings, even due to lack of time in the face-to-face meetings. Conversely, within the WhatsApp group, these events occur frequently. This finding is in line with another study of a WhatsApp group of a community of science teachers in a middle school in Turkey (Cansoy, 2017). Hands, Guzar, and Rodrigue (2016) found that the facilitators in a teachers' PLC emphasized that encouraging members was the key to their success because it gave members more confidence as they progressed with their work. By providing the learning communities with encouraging feedback as a group norm, this element of the group's culture holds promise for PLC development. A study by Karapanos et al. (2016) points out that the ability to craft the message and its timing on WhatsApp allows members to express their emotions, without the interruptions and the uncomfortable feeling that might occur in a face-to-face meeting, while enabling them to iterate on the content created until the optimal result is achieved.

We recommend using the possibility of crafting the message for giving reinforcement and honor, that build the identity of the LT, by giving credit to members who share meaningful items such as links, animations, interesting articles, activities in the classroom, and student projects, which enable other members to learn from and draw inspiration and new ideas. The CFs should visit and observe the members leading CtH meetings and give them public reinforcement accordingly, as well as publicize events, meetings, and special activities led by members, announce prizes they have received or their other achievements.

5.4 In Terms of a Shared Emotional Connection

The element of a shared emotional connection is reflected by the intensity of the group interactions that were expressed in the many messages posted. In other words, the members of the community have been together for a long time in virtual space, so there was a high probability of a significant connection being established between them. WhatsApp promotes the intensity of the interaction, in terms of the number of messages over time, so it supports creating additional contacts. As was found before, WhatsApp is a place where the teachers are present anyhow, and it represents a natural, convenient meeting point (Hershkovitz, Forkosh-Baruch, & Ang, 2014; Thoms & Eryilmaz, 2014).

Regarding the quality of the interactions, most of the events in the WhatsApp discourse were in a professional context and were mostly about substantive issues on chemistry teaching (Blonder & Waldman, 2019). Through the WhatsApp group, important events can be brought to a meaningful closure (see Fig. 7). The WhatsApp group provides a good platform for concluding an event through reflection, posting pictures, expressing appreciation to members, and thanking peers for the great effort invested and for its success; thus, it creates the narrative of the group.

O'Hara et al. (2014) described how WhatsApp exchanges turn to group commentary and reflection about the shared events: "Photos are exchanged, social interactions are played over, critiqued, and analyzed, and playful teasing carried out - all ways of participating in the group's ongoing narrative construction" (p. 8). They stress the role of WhatsApp in creating a shared emotional connection: "It is togetherness and intimacy enacted through small, continuous traces of narrative, of tellings and tidbits, noticing and thoughts, shared images and lingering pauses. This friendship has a history and an ongoing trajectory into the future. It has a rhythm whereby people are coming together and then parting knowing they will come back not to the same space but through the next act of communication, the next expression of 'what's happening'" (p. 11).

5.5 SoC in the Online Platform

The WhatsApp group was opened by the CF, in order to enable and promote communication among the PLC members in between meetings. In line with other findings, we can see that the existence of the WhatsApp group supported the development of a sense of community. Bouhnik and Deshen (2014), in their research on joint teacher-student WhatsApp groups, found that teachers reported that the groups enabled promoting a positive atmosphere and a sense of belonging in class, whereas the open style of discussion enabled the teachers to get to know their students in depth. Another example of the influence of an online social network was reported by Davis (2015) in his work on teachers' perception of Twitter for professional development. He found that one of the main themes that emerged from teachers' interviews was that teachers experienced a sense of belonging through engagement in Twitter. In another study dealing with preservice teachers' perceptions of the impact of Instant Messaging on the development of community among them, similar results were obtained, indicating that instant messaging enhanced the sense of community experienced by the cohorts (Doering, Cynthia, George, & Nichols-Besel, 2008). Our results support these studies and are in line with Garrison's notion of social presence (Garrison, Anderson & Archer, 1999), which implies that the WhatsApp group, which includes text-based tools, pictures, and videos, is a social network that facilitates the building of social relationships, personal connections, and a sense of belonging.

In conclusion, the PLC model, whereby teachers engage in collaborative learning, make their teaching practice public to one another, and share knowledge can only take place if the teachers have a real sense of community. Thus, we wish to emphasize the sense of community in the operating model of the communities, both in real life meetings and in the WhatsApp group, as an online social network environment.

The integration of the online component creates a new type of social space in which members can learn and socialize together across boundaries of time and place. The value of an online community for educators lies in the rich and open exchange of ideas, experiences, and resources where educators feel both respected and supported (Booth, 2012). Our findings show that the discourse in the WhatsApp group can support the building of all four elements needed for creating a SoC. We suggest that analyzing the WhatsApp discourse can be used as a diagnostic tool for evaluating the SoC of communities being studied. In the current study, we found that the SoC of the leading chemistry teachers to the community is high. We believe that the described support mechanisms can be enhanced by the group facilitators. We propose that this form of sociality could also be manifested in other online applications.

5.6 Challenges

Despite the great advantages of the use of WhatsApp, the analysis of the discourse reveals several challenges. As can be seen in Fig. 1, many messages are sent to the group at all waking hours. This leads to the first challenge: the loading of many messages that can be irrelevant; not all the events of the conversation interest everyone equally. When the messages arrive at night, the boundaries between work and home become blurred, and as a result, there is also a high expectation that the leading team will be available. Similar results were also observed by Bouhnik and Deshen (2014) and Davis (2015).

The second challenge concerns the fact that most of the publications and photos in the WhatsApp group are beautiful and positive, giving the mistaken impression that everyone is doing very well all the time; consequently, someone may feel that he is the only one who is not doing well. The norm in social networking is to show mainly good things and successes. According to our results, although the CF established norms in which showing difficulties and asking questions are legitimate, only limited events in which members ask questions were identified.

Another problem we identified is that there can be a feeling that one is not being seen, when one has published something and no one has answered or only a few responses have been received.

5.7 Limitations

It is important to note that here, SoC was analyzed in the WhatsApp group and other important processes that occurred and were supported in the WhatsApp group were not discussed. These include the professional development of the teachers in the community, aspects of teachers' knowledge, and the identity of the LTs. These will be described elsewhere. The teachers' SoC was researched for a unique group of teachers: the leading chemistry teachers. Therefore, the generalization of the findings should be carried out carefully. However, we made several recommendations for facilitators of teachers' WhatsApp groups, which were presented in the Discussion. These recommendations could enable the facilitators of the WhatsApp group to maximize the influence of WhatsApp on SoC.

Acknowledgements This research was supported by the Trump Foundation [grant numbers 154]; the National Chemistry Teachers' Center the Ministry of Education [Tender: 09.07.13]. We would like to thank the leading team of the chemistry PLC: Dr. Dvora Katchevich, Dr. Malka Yayon, Dr. Rachel Mamlok-Naaman, Mrs. Sara Ekons, Dr. Shelley Rap, and Mrs Enas Easa.

References

Aurami, A. (2017). *Why communities of practice?* Retrieved from http://www.enliveningedge.org/tools-practices/are-you-in-the-community-you-really-want/

Avidar, R., Ariel, Y., Malka, V., & Levy, E. C. (2013). Smartphones and young publics: A new challenge for public relations practice and relationship building. *Public Relations Review, 39*(5), 603–605.

Baym, N. K. (1995). The emergence of community in computer-mediated communication. In *CyberSociety: Computer-mediated communication and community* (pp. 138–163). Thousand Oaks, CA: Sage.

Blonder, R., & Waldman, R. (2019). The role of a WhatsApp Group of a Professional Learning Community of chemistry teachers in the development of their knowledge. In *Mobile Technologies in Educational Organizations* (pp. 117–140). IGI Global.

Booth, S. E. (2012). Cultivating knowledge sharing and trust in online communities for educators. *Journal of Educational Computing Research, 47*(1), 1–31.

Bouhnik, D., & Deshen, M. (2014). WhatsApp goes to school: Mobile instant messaging between teachers and students. *Journal of Information Technology Education: Research, 13*, 217–231.

Cansoy, R. (2017). Teachers' professional development: The case of WhatsApp. *Journal of Education and Learning, 6*(4), 285.

Church, K., & de Oliveira, R. (2013). *What's up with WhatsApp?: Comparing mobile instant messaging behaviors with traditional SMS.* Paper presented at the Proceedings of the 15th international conference on Human-computer interaction with mobile devices and services.

Cochran-Smith, M., & Lytle, S. L. (1999). Relationships of knowledge and practice: Teacher learning in communities. *Review of Research in Education, 24*, 249–305.

Coutinho, C. P., & Lisbôa, E. S. (2013). Social networks as spaces for informal teacher professional development: Challenges and opportunities. *International Journal of Web Based Communities, 9*(2), 199–211.

Darling-Hammond, L., & Sykes, G. (1999). *Teaching as the learning profession: Handbook of policy and practice*. San Francisco, CA: Jossey-Bass.

Davis, K. (2015). Teachers' perceptions of Twitter for professional development. *Disability and Rehabilitation, 37*(17), 1551–1558.

Doering, A., Cynthia, L., George, V., & Nichols-Besel, K. (2008). Preservice teachers' perceptions of instant messaging in two educational contexts. *Journal of Computing in Teacher Education, 25*(1), 5–12.

Fincher, S., Dziallas, S., Brandes, O., Kolikant, Y. B.-D., & Shapiro, R. B. (2016). *Negotiating academic communities: Narratives of life-long learners*. Singapore, Singapore: International Society of the Learning Sciences.

Garrison, D. R., Anderson, T., & Archer, W. (1999). Critical inquiry in a text-based environment: Computer conferencing in higher education. *The Internet and Higher Education, 2*(2–3), 87–105.

Garrison, D. R., & Arbaugh, J. B. (2007). Researching the community of inquiry framework: Review, issues, and future directions. *The Internet and Higher Education, 10*(3), 157–172.

Grossman, P., Wineburg, S., & Woolworth, S. (2001). Toward a theory of teacher community. *The Teachers College Record, 103*, 942–1012.

Hands, C., Guzar, K., & Rodrigue, A. (2016). The art and science of leadership in learning environments: Facilitating a professional learning community across districts. *Alberta Journal of Educational Research, 61*(2), 226–242.

Hershkovitz, A., Forkosh-Baruch, A., & Ang, R. P. (2014). *"I miss my students": Characterizing teachers seeking connection with their students via social networking sites.* Paper presented at the EdMedia: World conference on educational media and technology.

Hofstein, A., Carmi, M., & Ben-Zvi, R. (2003). The development of leadership among chemistry teachers in Israel. *International Journal of Science and Mathematics Education, 1*, 39–65.

Kaplan, A. M., & Haenlein, M. (2010). Users of the world, unite! The challenges and opportunities of social media. *Business Horizons, 53*(1), 59–68.

Karapanos, E., Teixeira, P., & Gouveia, R. (2016). Need fulfillment and experiences on social media: A case on Facebook and WhatsApp. *Computers in Human Behavior, 55*, 888–897.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, UK: Cambridge University Press.

Leana, C. R. (2011). The missing link in school reform. *Stanford Social Innovation Review, 9*(4), 30–35.

Macià, M., & García, I. (2016). Informal online communities and networks as a source of teacher professional development: A review. *Teaching and Teacher Education, 55*, 291–307.

McMillan, D. W. (1996). Sense of community. *Journal of Community Psychology, 24*(4), 315–325.

McMillan, D. W., & Chavis, D. M. (1986). Sense of community: A definition and theory. *Journal of Community Psychology, 14*, 6–23.

Mezirow, J. (1997). Transformative learning: Theory to practice. *New Directions for Adult and Continuing Education, 1997*(74), 5–12.

Miles, M. B., Huberman, A. M., & Saldana, J. (2013). *Qualitative data analysis*. Los Angeles, CA: Sage.

Moore, R. L. (2014). Importance of developing community in distance education courses. *TechTrends, 58*, 20.

Nisbet, R. A., Perrin, R. G., & Page, C. H. (1977). *The social bond*. New York, NY: Alfred A. Knopf.

O'Hara, K. P., Massimi, M., Harper, R., Rubens, S., & Morris, J. (2014). *Everyday dwelling with WhatsApp.* Paper presented at the Proceedings of the 17th ACM conference on computer supported cooperative work & social computing.

Rap, S., & Blonder, R. (2016). Let's Face(book) it: Analyzing interactions in social network groups for chemistry learning. *Journal of Science Education and Technology, 25*(1), 62–76. https://doi.org/10.1007/s10956-015-9577-1

Rheingold, H. (1993). *The virtual community: Finding connection in a computerized world*. Chicago, IL: Addison-Wesley Longman.

Rovai, A. P. (2002). Development of an instrument to measure classroom community. *The Internet and Higher Education, 5*, 197–211. https://doi.org/10.1016/S1096-7516(02)00102-1

Salazar, D., Aguirre-Muñoz, Z., Fox, K., & Nuanez-Lucas, L. (2010). On-line professional learning communities: Increasing teacher learning and productivity in isolated rural communities.

Seufert, M., Schwind, A., Hoßfeld, T., & Tran-Gia, P. (2015). *Analysis of group-based communication in WhatsApp.* Paper presented at the International conference on mobile networks and management.

Seufert, M., Hoßfeld, T., Schwind, A., Burger, V., & Tran-Gia, P. (2016). Group-based communication in WhatsApp. Paper presented at the 2016 IFIP networking conference (IFIP networking) and workshops.

Shulman, L. S. (1997). *Communities of learners & communities of teachers*. Jerusalem, Israel: Mandel Institute.

Shulman, L. S., & Sherin, M. G. (2004). Fostering communities of teachers as learners: Disciplinary perspectives. *Journal of Curriculum Studies, 36*(2), 135–140.

Stat, N. (2016). *WhatsApp has grown to 1 billion users*. Retrieved from https://www.theverge.com/2016/2/1/10889534/whats-app-1-billion-users-facebook-mark-zuckerberg

Strauss, A., & Corbin, J. (1998). *Basics of qualitative research: Techniques and procedures for developing grounded theory* (2nd ed.). Thousand Oaks, CA: Sage.

Thoms, B., & Eryilmaz, E. (2014). How media choice affects learner interactions in distance learning classes. *Computers & Education, 75*, 112–126.

Tinto, V. (1993). Building community. *Liberal Education, 79*(4), 16–21.

Tschannen-Moran, M. (2014). *Trust matters: Leadership for successful schools*. Hoboken, NJ: Wiley.

Tschannen-Moran, M., & Gareis, C. R. (2015). Principals, trust, and cultivating vibrant schools. *Societies, 5*, 256–276. https://doi.org/10.3390/soc5020256

Ruth Waldman holds bachelor and master degrees in chemistry and a teaching certificate. She has been teaching high school level chemistry for 20 years, and serving as coordinator of chemistry studies in her school. She has also served as regional instructor for chemistry teachers in behalf of the ministry of education. Currently she is a doctoral student at the Weizmann Institute of Science, specializing in the professional development of chemistry teachers in teacher communities, investigating the development of knowledge, the sense of community and identity among the teachers participating in the communities. As part of her PhD studies she takes an active role in the network of chemistry teachers' PLC, which was established in Israel for supporting the Professional Development of chemistry teachers. In these PLCs, chemistry teachers meet face-to-face on a regular basis and systematically reflect upon their knowledge and practice in order to improve their teaching. In this network, she was at first one of the lead teachers and then became one of the community facilitators.

Prof. Ron Blonder is a professor of science education and the head of the chemistry group in the Department of Science Teaching, Weizmann Institute of Science. The goal of Prof. Blonder's research group is to bring the chemistry of tomorrow into the high school chemistry lessons of today. Her research addresses three issues: nano-scale science and technology education; science teachers' self-efficacy; and, chemistry teachers' professional development. Her efforts to enhance chemistry teachers' professional development has reached a large number of chemistry teachers via the National Chemistry Teachers' Center, the Rothschild-Weizmann program, the Israeli Chemical Society, EU-projects, and through the Professional Learning Communities net for chemistry teachers in Israel. She led the Weizmann Institute's team in the Irresistible project, FP-7 EU-project dealt with responsible research and innovation (RRI) for high school science. Professional site: http://www.weizmann.ac.il/st/blonder/

From Practice to Practical: Computer Science Teachers Teaching Teachers

Ofra Brandes, Yifat Ben-David Kolikant, and Catriel Beeri

1 Introduction

The twenty-first century schools are challenged with continuous changes, hence teachers are expected to adjust rapidly to new contents and pedagogical philosophies they did not encounter neither as students nor as prospective teachers. Moreover, the teachers are expected to adapt to these changes, implement them in their practice, and become life-long learners. Understanding how to best support teachers at the times of change has become more important now than ever before (Bransford, Darling-Hammond, & Lepage, 2005; Day, 2012).

Consequently, in recent decades there is an increasing interest in supporting teachers' peer teaching (Dogan, Pringle, & Mesa, 2016; Hattie, 2003; Henze, Van Driel, & Verloop, 2008; Loughran, Berry, & Mulhall, 2012; Popp & Goldman, 2016; Shulman, 2002; Shulman, 2007). The assumption is that effective teachers have a unique knowledge that they developed throughout their career, sometimes called "wisdom of practice" (Hattie, 2003; Loughran et al., 2012; Shulman, 1986). This knowledge is potentially of great value to their peers. Hence, fostering the professional interactions between these teachers and their peers can bring about an improvement in teaching, and ultimately help the teachers to cope with innovations and reforms. However, there is limited empirical evidence about how teachers process their knowledge—the pedagogical decisions they make regarding what knowledge to use and how to use it, when teaching their peers. Shedding light on this knowledge and the process underlying it, can enable effective and meaningful

---

O. Brandes (✉) · Y. Ben-David Kolikant
Seymour Fox School of Education, Hebrew University of Jerusalem, Jerusalem, Israel
e-mail: ofra.brades@mail.huji.ac.il; yifat.kolikant@mail.huji.ac.il

C. Beeri
Dan Academic Center, Petach-Tikva, Israel

Y. Ben-David Kolikant et al. (eds.), *STEM Teachers and Teaching in the Digital Era*, https://doi.org/10.1007/978-3-030-29396-3_8

activation and use of this unique knowledge in order to get the most out of it (Berry & Van Driel, 2012; Hanuscin, Menon, Lee, & Cite, 2011).

In this work we address this need, focusing on Computer Science (CS) teachers. As much as the twenty-first century education, CS teaching is characterized by the great instability (Roberts, 2004). CS teachers have to adjust rapidly to new paradigms, concepts, ideas, technological environments, and pedagogical approaches. Moreover, they need to teach new knowledge that they neither learned at a university nor experienced as programmers, let alone taught before in school (Gal-Ezer & Stephenson, 2014).

Israeli CS teachers are no exception (for a detailed description of the Israeli educational context and CS curricula see Sect. 3.1). Specifically, in 2008, the CS high-school curriculum in Israel underwent a dramatic change, from procedural to object-oriented programming (OOP). Teachers had to adopt the new programming paradigm and to start teaching the revised unit in their classrooms within a year or two.

The Israeli Ministry of Education assigned a team of computer scientists, curriculum developers, and CS teachers to develop teaching materials (textbooks, teacher guides, laboratory sessions, and so forth), which were available to the teachers (Brandes, Vilner, & Zur, 2010). Additionally, as part of the dissemination efforts, experienced teachers with basic knowledge in OOP were recruited to a course entitled *CS Leading Teacher Course* (CS-LTC) (for details, see Sect. 3.2). In the course, these teachers studied advanced topics in OOP and discussed pedagogical issues related to the new curriculum. As part of the course requirements, the teachers had to conduct workshops (WSs) for peer teachers concerning the pedagogy of the new curriculum (for details on the workshops see Sect. 3.1). The work reported here was part of a bigger research project, where we had studied the impact of participating in the CS-LTC and the workshops on the course participants and on their knowledge processing. Elsewhere, we report on our findings regarding these teachers' conceptions of themselves and their roles as leading teachers (Brandes, Ben-David Kolikant, & Beeri, in preparation). In this paper, we report on our investigation into the knowledge these teachers chose to present (or not) to their peers in the workshops, how these teachers shaped this knowledge for the purpose of teaching their peers, and their justification of their choices.

2 Literature Review

2.1 Teachers' Knowledge

More than three decades ago, Lee Shulman (1986, 1987) coined the term Pedagogical Content Knowledge (PCK), to define the unique knowledge teachers of a domain develop throughout their work. Having this PCK distinguishes teachers from other experts in that domain as well as from teachers in other domains. For example, CS teachers have different knowledge than computer scientists, as well as from teachers in other domains (e.g., Mathematics). According to Shulman, PCK is the result of integration of content knowledge (CK) (also known as subject domain knowledge) and pedagogical knowledge (PK). It includes different types of knowledge, such as knowledge of curriculum, familiarity with students' learning, their needs and difficulties, and familiarity with the school context (Shulman, 1987). PCK involves a repertoire of teaching approaches, or as Shulman puts it:

> … ways of representing and formulating the subject that make it understandable for others. Since there is no single most powerful form of representation, the teacher must have at hand a veritable armamentarium of alternative forms of representation, some of which derive from research whereas others originate in the wisdom of practice. (Shulman, 1986, p. 9).

This repertoire also includes being aware of students' alternative conceptions, often referred to as misconceptions. PCK is therefore a complex kind of knowledge which teachers develop during years of teaching. Experienced teachers draw upon multiple knowledge types simultaneously as they make instructional decisions. Due to their rich PCK, experienced teachers are flexible, that is, they adjust and respond quickly to various situations that occur in their classroom and improvise when necessary. In contrast, novice teachers often have difficulties in producing good answers to students' questions, or bringing up (pedagogically effective) suitable examples to clarify challenging material (Berliner, 2001).

Shulman's notion of PCK has been revised and refined by him and other scholars over the years. Grossman (1989, 1990) compared the functioning of two groups of new teachers, those who underwent a teacher preparation program with emphasis on the development of PCK and those who did not. She found that the former group functioned better than the latter, because the teachers who developed PCK while preparing for their teaching have been constantly thinking about the following three questions: (a) Why do we teach this topic? (b) What should we teach? and, (c) What about the students? Namely, teachers who underwent the program had clear goals for their teaching; they chose carefully what to teach (all taught the same content, but approached it differently), taking into account both the first two goals and the characteristics of their students (e.g., difficulties and interests). These questions shape the choices teachers make by selecting a preferable option out of the repertoire of available pedagogical tools (Saeli, 2012; Saeli, Perrenet, Jochem, & Zwaneveld, 2011).

While it is widely agreed that PCK is an important concept, measuring PCK is not trivial. In fact, it has been criticized for being illusive (Depaepe, Verschaffel, & Kelchtermans, 2013; Loughran et al., 2012). Some criticized Shulman's original definition as undermining the action-oriented nature of teacher knowledge (see Depaepe et al., 2013 for a review of the critique). PCK may be perceived as a central element within a teacher's practical knowledge, which is action-oriented and person-bound. Practical knowledge is constructed by teachers in the context of their work and integrates formal knowledge, experimental knowledge, and teacher beliefs. These beliefs, in particular, play a very important role in building practical knowledge. In fact, beliefs are the filter through which new knowledge is interpreted and subsequently integrated in the teachers' existing knowledge (Abell, Appleton, & Hanuscin, 2010). This practical knowledge, to a great extent, is tacit, as teachers are not used to articulating their practical considerations; however, it is at the core of teachers' professionalism, of their professional practices (Loughran et al., 2012; Loughran, Mulhall, & Berry, 2004; Van Driel, Beijaard, & Verloop, 2001). As this practical knowledge grows, teachers become more adaptable and hence are able and willing to effectively address challenging situations in their teaching.

2.2 Teachers' Knowledge During Curricular Change

In time of curricular change and reforms, not only the teachers need to master new contents, teaching goals, and pedagogical approaches in short time, but also rapidly acquire and develop viable PCK, that is the knowledge how to best teach these contents, achieve the goals, and effectively apply the pedagogical approaches. Often there is a regression in the quality of the teachers' functioning in the classroom because of both the fragility of the knowledge they need to teach and the lack of relevant PCK (Day, 2012). Liberman, Ben-David Kolikant, and Beeri (2012) observed experienced CS teachers the first time they taught a new curriculum and found that indeed there was a regression in the teachers' functioning. The teachers could not effectively answer students' questions and flexibly build on classroom situations to enhance student learning. Nevertheless, the teachers did not function as would be expected from novices in such situations (Berliner, 2001; Lapidot, 2005). In particular, they were attentive to their students and encouraged them to ask questions, even though their own responses were not always effective. The teachers' recovery was fast: their fragile CK was quickly repaired and relevant PCK rapidly emerged. In the second year, the teachers made almost no CK-related mistakes and their pedagogical effectiveness (such as using appropriate analogies and effective examples) and adaptability to students' needs improved.

2.3 Peer Teaching as a Means to Cultivate PCK Growth in Time of Change

Interaction with peers can serve as a valuable resource for PCK growth. Explicating personal professional knowledge and sharing it with colleagues or student-teachers, can serve as an important key to effective teacher professional development (Dogan et al., 2016; Hattie, 2003; Henze et al., 2008; Loughran et al., 2012; Popp & Goldman, 2016; Shulman, 2002; Shulman, 2007). Interaction with peers is a means for teachers to enrich their repertoire and expand their flexibility.

In times of change, peer learning can serve as a supportive environment within which teachers discuss the required change and how to adapt to it (see the review by Dogan et al., 2016). Because of the valuable knowledge of experienced teachers, there is an interest in exploring the possibility of them becoming agents of change, a bridge between reform (or change) planners and other teachers. These experienced teachers can support the implementation of the reform by mediating its spirit to other teachers; they can serve as role models and guides in demonstrating how they adapted to the change and how to adapt to it (Day, 2012; Even, 1999; Hofstein, Carmi, & Ben-Zvi, 2003).

For these reasons, there is a wide interest in perusing ways to support teachers' peer teaching (Depaepe et al., 2013; Henze et al., 2008; Loughran et al., 2012). However, there is limited empirical evidence about how teachers process their knowledge when teaching their peers; how they filter and shape their knowledge in these situations. Plausibly, during peer teaching these teachers ponder (tacitly or explicitly) over the question of "what about the students?") Grossman, 1989), since teaching peers is different from teaching students. Several scholars highlight the importance of understanding the considerations, the meta PCK, in other words the "rules" underlying teachers' processing – filtering and shaping – of their knowledge for the purpose of teaching peers. These studies also highlight the complexity of revealing those rules and that little is known empirically about them (Berry & Van Driel, 2012; Depaepe et al., 2013; Hanuscin et al., 2011). This work addresses this need.

3 The Contexts of the Study

3.1 The Israeli CS Program for High School

Israel has a centralized education system. Israel's Ministry of Education determines the curricula for the whole country. At a high-school level, in addition to obligatory courses (e.g., Mathematics, English, and History), students have to study at least one expanded program of their choice. CS is one such program. The program consists of 450 h, and is divided into several modules, each of which covers a particular topic and contains one or more units of 90 h each. Students who take this program have to pass the Matriculation Exams for each module—the final exams administrated by the Ministry of Education. At the time data for this research were collected (2008), the Ministry of Education used a policy, in which about a month before the exam took place, a list of contents that were excluded from the exam was published. Apparently, this policy influenced the LT's decision what contents to teach and when.

As mentioned in Sect. 1, the study took place at a time of a dramatic change in the CS curriculum for high school. It was decided that the paradigm of OOP will gradually replace in the curriculum that of procedural paradigm. The first step in this process was to revise accordingly one unit, entitled "Data Structures". Consequently, the CS teachers had to prepare students for the matriculation in a paradigm which most of them had never learned. This change required the Ministry of Education to provide professional development for the CS teachers. To this end, experienced teachers with a good reputation, who already knew basic OOP, were recruited to a course entitled CS Leading Teachers Course (CS-LTC). To participate, these teachers had to meet three conditions: they had to (a) teach OOP in their own classroom for the first time that year; (b) participate in the CS-LTC meetings, and (c) conduct workshops to peers and help them to prepare for teaching OOP. The participation in

Table 1 Workshops scheduling and facilitators

Date	Relevant events	CS-LTC	Workshops				
Sept 2007	School Year						
		CS-LTC					
Oct 2007							
Nov 2007							
Dec 2007							
Jan 2008							
Feb 2008			WS1 Orna Nava	WS2 Alex Ilana			
					WS3 Irit Shmuel Adi		
Mar 2008							
Apr 2008							
May 2008							
						WS4 Hana Malka	
	matriculation						
June 2008							
							WS5 Ruth Amir
July 2008							
	Matriculation exam						

the course was voluntary – no incentives were given to the teachers. We will refer from now on to the CS-LTC participants as leading teachers (LTs). Five workshops took place during the school year, each of which started at a different time and was conducted by a different team of the CS-LTC teachers (see Table 1).

3.2 *The CS-LTC*

The CS-LTC was facilitated by the unit development team, whose head was the first author of this article. The CS-LTC included nine 6-h long meetings. In the first four meetings the LTs were introduced to the pedagogical considerations of the revised unit developers: their goals and the unit's "spirit"; namely, explicit and implicit assumptions underlying development decisions and other pedagogical considerations made by the design team. To this end, the CS-LTC participants were provided with two sets of PowerPoint presentations (PPTs). One set of slides was provided as an aid for all the teachers of the unit (as part of the curricular materials) and included the contents a teacher needs to teach (i.e., the CK). The second set was designed particularly for the CS-LTC. It integrated some CK with a lot of pedagogical considerations and the basic assumptions underlying the curricular unit.

The following two meetings were devoted to the design of the workshops. In these meetings, the LTs discussed the pre-requisites they would ask from the peers they were about to teach in the workshops, as well as the knowledge they can anticipate these peers have so that they can build on. Throughout these discussions, the LTs collectively produced another PPT, to be used in the opening session of the workshops, different from the PPTs they were provided.

Meetings 6–9 took place in parallel to three workshops (WS1-WS3) that already began. Substantial time was devoted to sharing experience from those workshops, discussing situations and difficulties, and formulating strategies to cope with these issues. The rest of the time was devoted to discussing the matriculation exam. In these meetings, The LTs discussed a variety of ways to teaching certain topics and the development of curricular materials (e.g., problems, exercises, thought-provoking questions).

3.3 Workshops

Table 1 provides the details of the teams (using pseudonyms) and the dates of each workshop. Each workshop consisted of seven meetings of 4 h each.

4 Research Goals and Research Question

When planning and conducting the workshops, the LTs had four main resources of PCK, they could have relied on: (a) their classroom experience, (b) the PCK discussed during the CS-LTC, (c) other LTs, especially the experience gained by their peers who already started the workshops, and (d) the development team. The richness of the knowledge resources enabled us to address the following research question: What were the rules that governed the LTs' choices, that is, their filtering and shaping of their knowledge for teaching their peers?

5 Methodology

5.1 Participants

Five workshops were conducted by twelve LTs, three male and nine female. These LTs were the research participants. Their ages ranged from 38 to 58. All of them had a B.Sc. and a teaching certificate. Three of them held post-graduate degrees, two held Master's and one had a Ph.D. We refer to them in this work, using pseudonyms (listed in Table 1). We will refer to the workshops' attendees, those teachers who were taught by the LTs (our study participants), as "teachers."

5.2 Data Sources

We used a qualitative, naturalistic approach (Lincoln & Guba, 1985) to capture the LTs' PCK and its growth. We aimed at capturing LTs' behavior in the particular situations (the CS-LTC and the WSs), in particular the knowledge expressed and choices made, and hence our main research tool was naturalistic observation (or observation without intervention) (Shaughnessy, Zechmeister, & Zechmeister, 2012). Specifically, we observed the meetings 5–9, where the LTs designed and discussed the WSs. Additionally, in each WS, we randomly sampled one or two meetings, as well as the closing meeting. The meetings observed were audio taped and transcribed. We also collected all the PPTs used in workshops.

In order to shed light on the underlying reasons we also collected the LT's email correspondence with the development team and conducted ad-hoc conversations when necessary. The multiple data sources enabled us to triangulate and validate our findings.

5.3 Research Methods

First, we compared the PPTs used in each workshop to the original presentation provided to the LTs during the CS-LTC. We examined what was omitted completely or partially and what was added or emphasized: we also examined the sequencing, and the fragility of the knowledge (e.g., slides with errors). This analysis enabled us to perform an initial characterization of each WS in terms of the pedagogical decisions made by the LTs. This comparison also enabled us to discern similarities and differences, from which we could determine the "rules" that governed LTs' filtering and shaping their knowledge.

Next, we analyzed the transcripts of the workshops and parts of the CS-LTC where the LTs discussed the workshops, focusing on the knowledge expressed (CK and PCK) and reasoning when provided. We developed a categorical scheme that expressed the essence of the knowledge: (a) filtering and shaping decisions, regarding both domain and pedagogical contents (omitted, added, revised and so forth), and (b) the pedagogical approaches evident in the workshops and the CS-LTC. Finally, the ad-hoc conversations with the LTs enabled us to further understand the findings obtained from the observations, in particular LTs' judgements underlying the rules.

6 Findings

A Comparison of the contents of the PPTs that were used in the CS-LTC to those the LTs used in their workshops showed that the number of pedagogical slides (e.g., the slides that present pedagogical considerations and guidelines how to teach and practice the topics) went down, while the number of slides containing exercises, solutions and content examples that "worked" in the LTs' classrooms, went up. It was also prominent that the LTs chose to omit pedagogical slides and to add slides with relevant CK.

6.1 Fragile Knowledge

During the workshops the fragility of the LT' knowledge was observed. For example, they often used concepts from the old curriculum (e.g., the procedural paradigm) that were inadequate in the context of the OOP paradigm. The LTs were aware of this fragility. They often corrected themselves during the workshops with help from their peers. These situations also led them to turn to the curriculum developers. The following quote from an email correspondence with Orna (WS1) demonstrates this fragility: "one teacher had a question that I couldn't answer…I'll be happy to have a certified answer".

In three workshops, we observed LTs using these situations as learning opportunities for the teachers who attended the WS. They initiated ad-hoc discussions with the teachers or provided ad-hoc tips as to how to deal with such situations in the classroom.

6.2 Flexibility and Pedagogical Considerations

Despite their fragile knowledge, LTs exhibited adaptive teaching in the workshops they have facilitated. Often, LTs' planning of the workshops was based on their classroom teaching experience. As they proceeded with their workshop teaching, however, they diagnosed the workshops attendees and adjusted accordingly, as exemplified in the following excerpt:

> In the meantime we are using [in the workshop] the phonebook [problem]. Trying it. I use it in my classroom as well. I think it helps the kids to understand. I thought that if it helps the kids it might do so for the teachers as well. (Ilana, WS2).

The phrases "in the meantime" and "trying" emphasize the uncertainty of Ilana about what she teaches, as well as her awareness of the need to adapt to teachers.

Indeed, the LTs often realized that the teachers' CK level is lower than they had expected and adjusted accordingly. For example, at some point, Orna (WS1) decided not to include a big programming project in the assignments for her teachers, although this big project is a central part of the curricular unit and although she required that from her classroom students:

> When we planned the first meeting I knew that there must be a big project to accompany the WS [as in the original curriculum]. I think it should come in addition and not instead of basic exercises. But at some point, I felt that we need to touch the important things. [if I do] this [big] project-- with all due respect— I won't have the time to do the main things.

Hence, the LTs' diagnoses of their workshop's audience yielded variations in the workshops. Variation was also noticed in LTs' decisions regarding lab sessions. The use of the computer lab is at the heart of the CS discipline. All the LTs reported that in their classrooms the laboratory sessions were central and that mastering this unit requires extensive laboratory time. In the CS-LTC discussions, the LTs all agreed that the CS lab is important also in the workshops, and reported that they tried to implement the same approach in their workshops. But, actually the workshops differed in the ways laboratory sessions took place and the time devoted to them. For example, "in order to make them [teachers in the WS] believe that it works we will put them in the laboratory. I think we cannot undermine its value" (Shmuel, WS3).

However, all LTs encountered difficulties in the workshops, which they ascribed to teachers' low motivation and low ability to practice OOP programming during the workshops. The LTs, in return, adjusted their plans. This quote by Ilana (WS2), taken from the CS-LTC discussion, exemplifies the difficulties encountered, the diagnosis made (the teachers have fragile CK), and the adjustments consequently made by LTs to address these difficulties.

> We decided that we need to train them [the teachers] in practice, because unfortunately, the teachers' situation is very bad. They all took Java [OOP language] courses, but did not actually use it. So they have no experience…they are totally rusted. In every WS session, we devote three quarters of an hour to work on a [laboratory] assignment. We prepare a skeleton and they have to fill in.

These case skeletons of programs that the teachers had to fill in were meant to help the teachers to focus on topics studied, and finish the lab on time.

Some LTs reported that teachers tried to skip the laboratory sessions, hence they scheduled the laboratory sessions to be in the middle between two other parts of a workshop meeting, thereby enforcing teachers to take part in the hands-on labs. However, in other workshops, laboratory sessions were reduced.

6.3 Knowledge Originating from the LTs' Classroom Practice

Despite the aforementioned differences in the contents of their PPTs and the variation observed during the workshops, all LTs preferred to rely in their teaching on the PCK they had tried in their classrooms, as demonstrated in Shmuel's excerpt taken from an ad-hoc conversation:

> We believe that what we didn't try in the classroom we cannot do in the WS. This is always in the background, we always tell the teachers 'it works at the students' level, **not** in a

> professional development course level or the books, it **works** with students. That sells well. [Bold denotes speaker emphasis of the words]

All LTs expressed a sense that their contribution to the teachers that participated in the workshops was unique. Specifically, the LTs considered their classroom experience with the curricular materials as a unique knowledge they have developed, knowledge that the workshops attendants, all in-service teachers, are interested in, and that is typically absent when a professional development course is handled by someone without this teaching experience, as Shmuel further explained:

> Several people told me that it is the first time that the [WS] guide really comes with background underlying [his or her WS] teaching, comes with [teaching] experience. This is in contrast to almost all other professional development [courses], where a professor or someone from the industry, or someone who knows programming. … And you see there is full attendance [in the WS], all the time.

6.4 Knowledge with Practical Relevance to the Teachers

Practicality emerged as an important rule that governs LTs' shaping their knowledge. The LTs pursued ways to provide knowledge in a ready-to-use-in-the-classroom form. To this end, they handed out work pages and summaries to the teachers, uploaded files with additional exercises to websites they had opened and distributed solutions to these exercises.

Often, the LTs had shared with their workshop teachers the pedagogical considerations that guided them in their own classrooms teaching, with the premise that this knowledge could be of immediate relevance to the teachers.

> In my classroom, in the chapter of linked list, I discussed the algorithms quite a lot, and I exercised those with them [my students] quite intensively, so that they will know how to work. It wasn't trivial. I remind you that next year you deal with the topic of linked lists. If you take the same approach, you'll see how convenient it is. (Shulamit, WS1)

Practicality also served as a filter. Contents not to be included in the matriculation exam were excluded from or postponed to the end of the workshops. For example, the topic of trees, an essential brick in programming, was postponed in WS3 to after the matriculation exam (from which it was excluded that year). The topic of map was excluded from all WSs. This topic does not appear in the syllabus, which is probably why they all omitted it. However, this topic was studied in the CS-LTC and was introduced to the LTs as an opportunity to exercise all the new contents. Yet, they all omitted it in their workshops. LTs explained that they felt they needed first to address the immediate needs of the teachers, as Shmuel explained in a CS-LTC meeting 8, devoted to discuss the workshops experience: "We felt that some of the teachers came [to WSs] because they wanted to get tools to help them deal with what they needed to do now. And there was a limited time till the matriculation exam".

Finally, all of the workshops included sessions about questions and problems to be used in the classroom. These sessions were inherently different from the sessions on questions in the CS-LTC. There, the focus was on the conceptual and theoretical differences between the new and the old matriculation exams and on the meaning of the phrasings of the questions. In the workshops, substantially more time was devoted to the topics and the focus was practical. The LTs developed new questions, prepared PPTs on the topic and engaged the teachers in various ways. For example, in WS2 teachers were divided into four teams of four or five each. Each team got one problem or a question and was asked to evaluate its clarity and level of difficulty, and if needed to revise it. They solved the problem, and prepared a rubric for evaluating student performance. The LTs explained that since the curriculum is new, teachers need questions to use in the classroom as well to practice the production and evaluation of questions and exercises.

6.5 Variation in Perceptions of the Teachers in the Workshops

Whereas the focus on practical knowledge and the filtering of knowledge from their practice were unifying themes, the LTs varied in their perceptions of and expectations from the teachers they were teaching in the workshops. During the preparation in the CS-LTC of the workshops, the LTs discussed the heterogeneity of teachers and the uncertainty they experience when planning.

Almost all of the LTs experienced the workshops' participants as suffering from insufficient programming skills. This is reflected, for example, in the email from Orna (WS1):

> [They are] diverse, including both veteran teachers and very young teachers in their first year of teaching. Only one teacher teaches this program [this year] and hence has a matriculation exam this year. The rest will start this program only in September [the beginning of next school year]. Some of the teachers have difficulties in the implementation [actual coding in the laboratory], they know the theory, [but are] very rusted in writing and executing in the [computer] environment. We prepared the laboratories so they can each choose the environment they are used to.

In all the workshops, as part of the adjustments, CK was added. For example, Shulamit (WS1) describes herself as being "shocked. Some here do not know how to program". Therefore, "after the first meeting, I developed a [PowerPoint] presentation that included contents that are supposed to be taught before this new unit and I also summarized the chapters." The LTs discussed *what* to teach given the heterogeneity on the one hand and the fear to insult the teachers on the other hand: "we hesitated whether we should bring the basic contents. After all, they are teachers. They have background" (Orna, WS1, in the CS-LTC).

The LTs had different expectations from the teachers in their workshops and different approaches to teaching them. In fact, there was a spectrum of perceptions of the teachers. On one pole were WS3 and WS2, where teachers were perceived as experienced teachers. This brought about the decision to build on their acquaintance with the CK and their PCK in CS. This is demonstrated in the frequent openings of new topics with phrases such as: "I assume that you know this topic so I am not going to teach it, only present it" and "this topic is known, concepts are the same, 'a node is a node'." In W2, the teachers were asked to produce deliverables that the LTs themselves had produced during the CS-LTC, such as exercises, examples, and lab assignments. Finally, in WS2 and WS3, teachers were also exposed to deeper, conceptually-oriented pedagogical considerations, such as the order of teaching the topics, as was done in the CS-LTC itself.

The LTs perceived the difficulties that the workshop participants experienced as natural, due to the need to learn and comprehend the new program, just as the LTs themselves experienced when they first had studied OOP: "I see me [in them] two years ago. This struggle, standing on the rear feet, not seeing the big picture, struggling with the little bits and not seeing the beauty of the essence of the change" (Adi, WS2).

On the opposite end of the spectrum was WS1. There teachers were perceived as students. In this workshop much time was devoted to teaching the CK, the time devoted to pedagogical considerations was rather low in comparison to W2 and W3. WS1 focused almost exclusively on immediate relevance and there were almost no thought-provoking questions regarding CK and PCK.

7 Discussion

The participants in this study, all experienced teachers with good teaching reputation, were put in a rather unique situation, where they prepared and taught workshops in OOP to their less experienced peers. They could rely on (a) their experience of teaching the new unit in their high-school classrooms, (b) their participation in the CS-LTC, where general knowledge about the new unit was extensively presented, followed by a discussion and preparation for the workshop, (c) the experience of other experienced teachers who also conducted workshops, and (d) the development team. This situation served as a valuable opportunity for us to examine the meta PCK of the LTs, namely the (unwritten) rules upon which they filtered and shaped their knowledge (CK and PCK) for the purpose of teaching their peers, a need recognized in the literature (e.g., Berry & Van Driel, 2012; Hanuscin et al., 2011).

7.1 Characteristics of the Knowledge Conveyed in the Workshops

The fragility of LTs' CK was expressed both in the programing mistakes and the tendency to use the "old", procedural terminology, which was not appropriate for the new paradigm. Apparently, this fragility did not serve as a filter when LTs chose what to teach. On the contrary, LTs used situations of fragility as a learning opportunity for the teachers in their workshops, and discussed with them how to behave in similar situations in their own classrooms. Moreover, LTs exhibited adaptability and extensive pedagogical judgement as they led the workshops. They used the materials they had previously used in their classrooms as a basis and adjusted the workshops as they became more familiar with the attendees.

The LTs varied in their perceptions of the teachers who participated in the workshops (their motivation, knowledge and skills), and that brought about a certain diversity in the workshops. One prominent difference was the length, content, and position of labs in the workshops; another prominent difference was the expectations from the attendees, which was expressed in the different tasks they required from the attendees and the amount of time devoted to discussing pedagogy vs that devoted to merely teaching the contents.

7.2 Practice to Practical: LTs' Meta-PCK

LTs *filtered* their CK and PCK, based on their own teaching experiences. They avoided teaching what they did not experiment with in their own classrooms. They each brought examples found to be useful in their own classrooms and furthermore announced that 'it worked' as a means to convince the teachers to use it. They valued their knowledge as unique and valuable to the workshops teachers. Perhaps their refusal to teach knowledge they have not experienced in class is an indicator of the fragility of this knowledge, a sense of discomfort, whereas their classroom practice provided a sense of comfort to teach even fragile knowledge.

The filtered knowledge described above, was *shaped* by the LTs in order to provide to their peers knowledge and tools in a ready-to-use in the classroom state. They all added sessions about exams and exercises. They excluded the more general pedagogical considerations, such as the sequencing of the textbook, and where and why to invest more time and effort. Their reasoning revolved around the immediate needs of the teachers who had to prepare students to the matriculation exam. As a matter of fact, the LTs experienced resistance and disengagement when they tried to move beyond the boundary set by this rule.

Based on this research, we suggest to name the process whereby, using filters and shapers LTs arranged a package of useable knowledge for teachers (workshop attendees) as 'practice to practical'. This new term emphasizes and supports the claim that teachers have unique viewpoints, agendas and beliefs according to which they filter and shape what and how they teach their peers (Abell et al., 2010). This term can illuminate and guide the way to reforms designers and teacher trainers.

Is practice-to-practical unique to the situation of this study in the CS discipline or is it common in situations when experienced teachers teach their colleagues? One would argue that the rule of practicality is due to the unique situation of in-service teachers who were put in a rather stressful situation. However, given that the LTs valued this knowledge as unique and important to their peers, future work is required to examine the scope of validity of this approach when teachers teach their peers in other situations. Is practice-to-practical enough for preparing the teachers who now have to teach the new unit? The vivid discussions during the CS-LTC, when pedagogical considerations underlying the curricular materials—such as the rationale of the curricular materials, the reasons for the sequencing, the goals of the specific phrasing of questions, and the necessity of big programming projects—were discussed, suggest that this knowledge was perceived by the LTs as useful and interesting. We believe that the teachers in the workshops would have benefited from the exposure to this PCK as well. Yet, LTs chose to omit this knowledge in the workshops. Participants' explanations that they felt that they need to address the immediate needs of the teachers and feared teachers' resistance to anything beyond the immediate practical relevance, are plausible. Future work is required to examine if a later, advanced professional development course, conducted after the teachers had taught the unit at least once, would be a better context for discussing this PCK and identify other conditions required, if at all.

8 Conclusions

In this work we identified, based on empirical observations, what teachers tend to pass onto their peers out of their arsenal of knowledge. Specifically, we characterized the knowledge that experienced CS teachers with solid teaching reputation chose to teach their peers. We found that these experienced teachers taught very specific knowledge out of their knowledge inventory, with the primary goal of practicality, preferring to rely mostly on their own classroom practice rather than on the knowledge they had practiced, developed and learned during a course designated to this matter.

Future research is required in order to examine whether this approach is unique to the situation examined, and reveal other filters and shapers, if indeed such exist, and the conditions in which these filters and shapers are chosen. Nonetheless, the findings of the present study are of special relevance for the research community concerned with the knowledge and professional development of teachers in the twenty-first century. It is an era in which, according to existing research, it is appropriate and valuable to make use of the wisdom of practice – the knowledge of experienced, veteran teachers to assist other teachers to successfully cope with ongoing curricular changes and innovations) Hattie, 2003; Loughran et al., 2012; Shulman, 1986, Shulman, 2002, Shulman, 2007).

References

Abell, S. K., Appleton, K., & Hanuscin, D. L. (2010). *Designing and teaching the elementary science methods course*. New York, NY: Routledge.

Berliner, D. (2001). Learning about and learning from expert teachers. *International Journal of Educational Research, 35*(5), 463–482.

Berry, A., & Van Driel, J. (2012). Teaching about teaching science: Aims, Strategies and backgrounds of science teacher educators. *Journal of Teacher Education, 64*(*2*), 117–128.

Brandes, O., Vilner, T., & Zur, E. (2010). *Software design course for leading CS in-service teachers* (Teaching fundamental concepts of informatics, Lecture Notes in Computer Science (LNCS 5941)) (pp. 49–60). Berlin, Germany/Heidelberg, Germany: Springer.

Bransford, J., Darling-Hammond, L., & Lepage, P. (2005). Preparing teachers for a changing world: What teachers should learn and be able to do. In L. Darling-Hammond & J. Bransford (Eds.). San Francisco, CA: Jossey-Bass.

Day, C. (2012). New lives of teachers. *Teacher Education Quarterly*, 7–26.

Depaepe, F., Verschaffel, L., & Kelchtermans, G. (2013). Pedagogical content knowledge: A systematic review of the way in which the concept has pervaded mathematics educational research. *Teaching and Teacher Education, 34*, 12–25.

Dogan, S., Pringle, R., & Mesa, J. (2016). The impacts of professional learning communities on science teachers' knowledge, practice and student learning: A review. *Professional development in education, 42*(4), 569–588.

Even, R. (1999). The development of teacher leaders and inservice teacher educators. *Journal of Mathematics Teacher Education, 2*(*1*), 3–24.

Gal-Ezer, J., & Stephenson, C. (2014). A tale of two countries: Successes and challenges in K-12 computer science education in Israel and the United States. *ACM Transactions on Computing Education, 14(2)*, Article 8, 18 pages.

Grossman, P. (1989). A study in contrast: Sources of pedagogical content knowledge for secondary English. *Journal of Teacher Education*, 24–31.

Grossman, P. (1990). *The making of a teacher: Teacher knowledge and teacher education.* (A. Lieberman, Ed.). New York, NY/London, UK: Columbia University/Teachers College Press.

Hanuscin, D. L., Menon, D., Lee, E. J., & Cite, S. (2011). *Developing PCK for teaching teachers through a mentored internship in teacher professional development*. Paper presented at the 2011 meeting of the Association for Science Teacher Education.

Hattie, J. (2003). *Teachers make a difference: What is the research evidence?* Australian Council for Educational Research Annual Conference on: Building Teacher Quality (October). University of Auckland.

Henze, I., Van Driel, J., & Verloop, N. (2008). Development of experienced science teachers' pedagogical content knowledge of models of the solar system and the universe. *International Journal of Science Education, 30*(10), 1321–1342.

Hofstein, A., Carmi, M., & Ben-Zvi, R. (2003). The development of leadership among chemistry teachers in Israel. *International Journal of Science and Mathematics Education, 1*, 39–65.

Lapidot, T. (2005). *Computer science teachers' learning during their everyday work.* Unpublished dissertation, Technion – Israel Institute of Technology (in Hebrew).

Liberman, N., Ben-David Kolikant, Y., & Beeri, C. (2012). *"Regressed experts" as a new state in teachers' professional development: Lessons from Computer Science teachers' adjustments to substantial changes in the curriculum.* https://doi.org/10.1080/08993408.2012.721663.

Lincoln, Y., & Guba, Egon G. (1985). *Naturalistic inquiry*. Beverly Hills, Calif: Sage Publications.

Loughran, J., Berry, A., & Mulhall, P. (2012). *Understanding and developing science teachers' pedagogical content knowledge* (2nd ed.). Sence Publishers.

Loughran, J., Mulhall, P., & Berry, A. (2004). In search of pedagogical content knowledge in science: Developing ways of articulating and documenting professional practice. *Journal of Research in Science Teaching, 41*(4), 370–391.

Popp, J. S., & Goldman, S. R. (2016). Knowledge building in teacher professional learning communities: Focus of meeting matters. *Teaching and Teacher Education, 59*, 347–359.

Roberts, E. (2004). *The dream of a common language: The search for simplicity and stability in computer science education*. SIGCSE'04, March 3–7. Norfolk, VA.

Saeli, M. (2012). *Teaching programming for secondary school: A pedagogical content knowledge based approach*. Technical University Eindhoven.

Saeli, M., Perrenet, J., Jochem, W., & Zwaneveld, B. (2011). Teaching programming in secondary school: A pedagogical content knowledge perspective. *Informatics in Education, 10*(1), 73–88.

Shaughnessy, J., Zechmeister, E. B., & Zechmeister, J. S. (2012). *Research methods, in psychology* (Ninth ed). New York: McGraw-Hill.

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harward Educational Review, 57*(1), 1–21.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.

Shulman, L. S. (2002). Truth and consequences? Inquiry and policy in research on teacher education. *Journal of Teacher Education, 53*(3), 248–253.

Shulman, L. S. (2007). Practical wisdom in the service of professional practice. *Educational Researcher, 36*(9), 560–563.

Van Driel, J., Beijaard, D., & Verloop, N. (2001). Professional development and reform in science education: The role of teachers' practical knowledge. *Journal of Research in Science Teaching, 38*(2), 137–158.

Ofra Brandes (PhD) is a postdoctoral researcher in the Department of Science Teaching at Weizmann Institute of Science. She currently serves as a lecturer in the Hebrew University's Teaching Certificate Program (in computer science teaching) and she leads the computer science professional learning communities in Israel. Her research interest revolve around computer science K-12 teachers, their knowledge growth and their professional development processes.

Yifat Ben-David Kolikant is an Associate Professor in the Seymor Fox School of Education, Hebrew University of Jerusalem. Her academic work is devoted to theorizing learning, teaching, and schooling in the age of globalization and digitalism, an age characterized by the ubiquity of digital technology, an information explosion, pluralism, and rapid changes. Over the past few years, she has dealt with two core questions: (a) How does digital technology influence schooling and (b) how can effective teaching environments be characterized? In recent years she has been involved in several studies aimed at understanding and enhancing in-service teacher learning under conditions of dramatic curricular and policy changes, and the role that ICT plays and should play in it. Prof. Ben-David Kolikant holds a Ph.D. degree in science teaching from the Weizmann Institute of Science, received in 2002.

Catriel Beeri is Professor Emeritus at the School of Engineering and Computer Science, the Hebrew University. His main research interest over the years has been database systems. An additional interest is the development of educational programs and materials in Computer Science for the secondary school system, and following their adoption.

Motivators, Contributors, and Inhibitors to Physics Teacher-Leaders' Professional Development in a Program of Professional Learning Communities

Smadar Levy, Esther Bagno, Hana Berger, and Bat-Sheva Eylon

1 Introduction and Theoretical Frameworks

A central factor in developing a sustainable, scalable teachers' PD program is the ability to prepare teacher-leaders who can implement the program with integrity and adapt it to local contexts while maintaining consistency with core principles (Borko, 2004). Our PLCs' program has been operating since 2012 and addresses the challenges of teaching physics, as advocated by current science education reforms, e.g., how to be more learner-centered, how to combine practices of science inquiry with core ideas and concepts of science (XE "Research" National Research XE "Research" Council, 2012), and how to promote collaborative learning and ownership of learning physics (Klentschy, 2008; Milner-Bolotin, Egersdorfer, & Vinayagam, 2016; National Academies of Sciences, 2015). Other challenges for high-school physics teachers include countering students' belief that learning physics is difficult (Madsen, McKagan, & Sayre, 2015), which consequently reduces the number of students who choose to major in it. Furthermore, in many schools the physics teachers have no colleagues for consultation and support (Etkina, Gregorcic, & Vokos, 2017; Meltzer, 2011; Scherr, Plisch, & Goertzen, 2017).

Teachers' PD is discussed in many studies, and it is widely agreed that effective PD programs should be ongoing, challenging, focused on student learning, and situated in teachers' practice (Borko, Jacobs, & Koellner, 2010; Darling-Hammond & Richardson, 2009; Desimone, 2009; Eylon & Bagno, 1997; Timperley, Wilson, Barrar, & Fung, 2008). It is recommended that teachers' PD be based on authentic evidence from classes and on collaborative examination of students' works in order to encourage teachers to consider changes in their practice (Eylon, Berger, & Bagno, 2008; Feiman-Nemser, 2001; Whitcomb, Borko, & Liston, 2009).

S. Levy (✉) · E. Bagno · H. Berger · B.-S. Eylon
The Science Teaching Department, Weizmann Institute of Science, Rehovot, Israel
e-mail: esther.bagno@weizmann.ac.il; hana.berger@weizmann.ac.il

Y. Ben-David Kolikant et al. (eds.), *STEM Teachers and Teaching in the Digital Era*, https://doi.org/10.1007/978-3-030-29396-3_9

PLCs are an essential component of high-quality PD (Bolam et al., 2005; DuFour, 2004; Little, 2012) and provide opportunities for teachers to actively and passionately investigate their teaching, consistently reflect on their practice and its consequences, and learn from one another (Grossman, Wineburg, & Woolworth, 2001; Shulman, 1997). Through PLCs teachers receive the support they need in order to advance their knowledge, their practice, and their views (Koellner, Jacobs, & Borko, 2011; Vescio, Ross, & Adams, 2008).

Theoretical frameworks for research on teachers-leaders' PD should take into consideration the multiple contexts of teacher-leaders' practice: as members of the teacher-leaders' PLC, as teachers, and as regional PLC leaders. Situative perspectives serve as a powerful research tool, taking into account both the individual teacher-learners and the social systems in which they participate, including PLCs (Borko, 2004; Putnam & Borko, 2000). Teacher change is a gradual and difficult process (Eylon & Bagno, 2006). Guskey (1986, 2002), who developed a model of teacher change process, emphasized that the three major goals of PD programs are to make: (1) changes in teachers' classroom practices, (2) changes in their attitudes and beliefs, and (3) changes in students' learning outcomes. In his model, Guskey underscored the importance of understanding the sequence in which these changes most frequently occur.

Clarke and Hollingsworth (2002) also proposed that in order to facilitate teachers' PD, one must understand the process by which teachers grow professionally, and the conditions that support and promote that growth. They suggested the perspective of teachers as active learners who shape their professional growth through reflective participation in PD programs and in practice. Their *Interconnected Model of Professional Growth* (shown in Fig. 1) recognizes the complexity of teachers' professional growth by identifying multiple growth pathways. According to this model, four distinct domains encompass the teacher's world: the Personal Domain, referring to teacher knowledge, beliefs and attitudes; the Domain of Practice, referring to professional experimentation; the Domain of Consequence, referring to salient outcomes, such as student learning or student motivation, and changes at school level; and the External Domain, referring to sources of information, stimulus or support. In the context of PD, the external domain may include input from facilitators, literature, peers and so on.

The model suggests that a change in one domain is translated into another domain through the mediating processes of "reflection" and "enactment" that are represented in the model as arrows linking the domains. Any processes of professional growth occur within the constraints and affordances of the enveloping change environment, e.g., facets of the school environment and opportunities to participate in a PD program (Clarke & Hollingsworth, 2002**).**

Teacher-leaders need both the knowledge and practice base to facilitate teachers' PD (York-Barr & Duke, 2004). Working with teachers as adult learners is a huge challenge for teacher-leaders and it greatly differs from their experience with students (Timperley et al., 2008).

In order to study the professional growth of the teacher-leaders in our program, and to identify the factors that motivate, contribute to, or inhibit their professional growth, we extended Clarke and Hollingsworth' *Interconnected Model of*

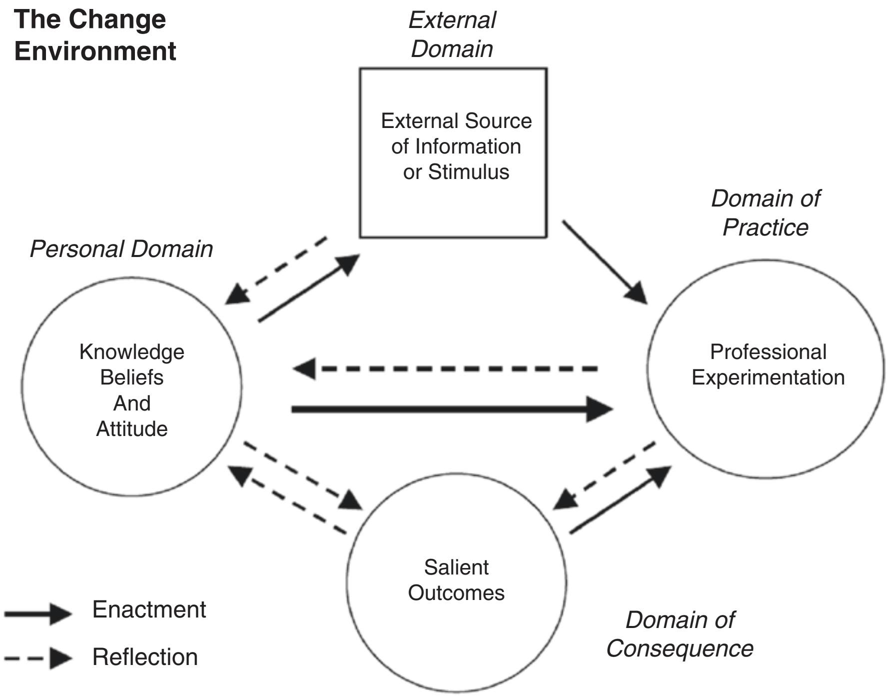


Fig. 1 The Interconnected Model of Professional Growth (Clarke & Hollingsworth, 2002)

Professional Growth and adjusted it to the professional world of physics teacher-leaders. In our *Extended Interconnected Model of Professional Growth* (EIMPG) (shown in Fig. 2) the Personal Domain relates to teacher-leaders' knowledge, beliefs, and attitudes as a teacher, a PLC member, or a PLC leader. The Domain of Practice consists of four subdomains of professional experimentation. Three subdomains represent experimentations in different contexts of teacher-leader's activity: as a teacher in class, as a teacher in school, and as a teacher-leader in a regional PLC. The fourth subdomain relates to the teacher-leader's experimentation with new technological tools for teaching (e.g., Google Forms, collaborative documents, and computerized lab-sensors); this is an important aspect of teaching physics.

The Domain of Consequence consists of salient outcomes in different contexts: the teacher-leader's classrooms, the teacher-leader's school, the regional PLC, and the PLC teachers' classrooms. In the External Domain, the PD program and the teacher-leaders' PLC are the sources of information, stimulus, and support. The Change Environment relates to the different contexts of the teacher-leaders' work, and the different factors that affect their professional growth.

Although it is widely agreed that teacher-leaders play a major role in teachers' PD and in the development of effective PLCs (van Driel, Meirink, van Veen, & Zwart, 2012; York-Barr & Duke, 2004), little is known about the factors influencing the development of science teacher-leaders (Lewthwaite, 2006). Moreover, pro-

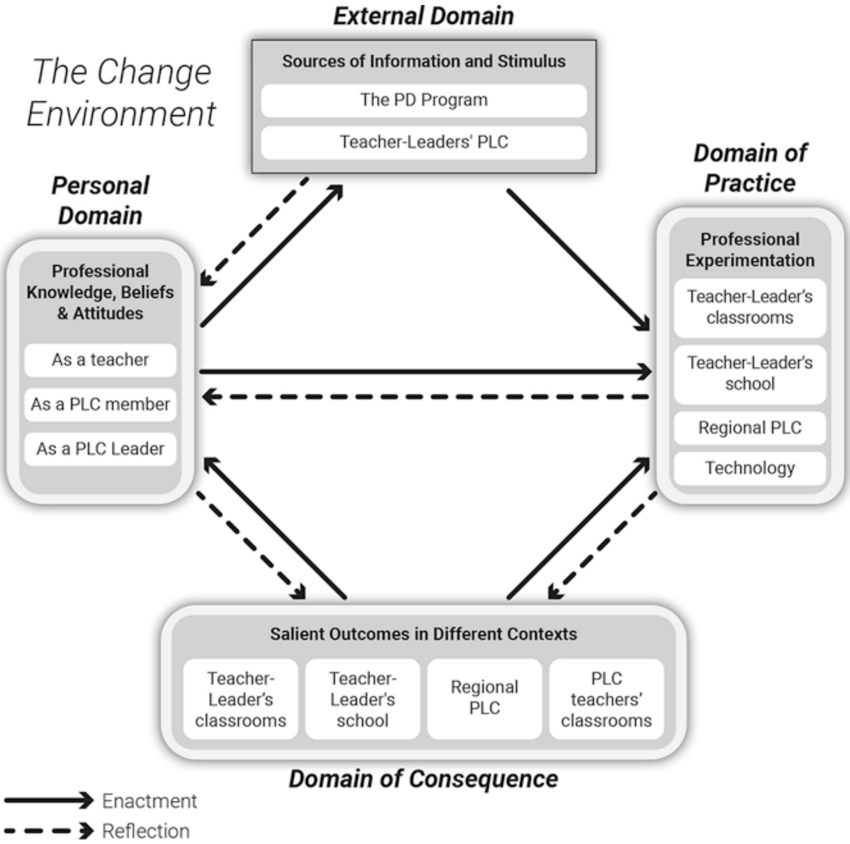


Fig. 2 The Extended Interconnected Model of Professional Growth (EIMPG)

grams for the PD of the teachers-leaders themselves are rarely discussed in the literature (Borko, Koellner, & Jacobs, 2014; Even, 2008; National Academies of Sciences, 2015; Neumerski, 2013).

This study is part of a larger study aimed at bridging this gap. Our goal is to study the professional growth of the teacher-leaders in our PLCs' program, and to identify the factors that motivated, contributed to, or inhibited their professional growth.

2 The Study

2.1 The Study's Context

The main objectives of our PLCs' national program are to enable physics teachers to examine collaboratively their teaching as well as their students' learning, and to promote responsive teaching and learner-centered instructional strategies. The pro-

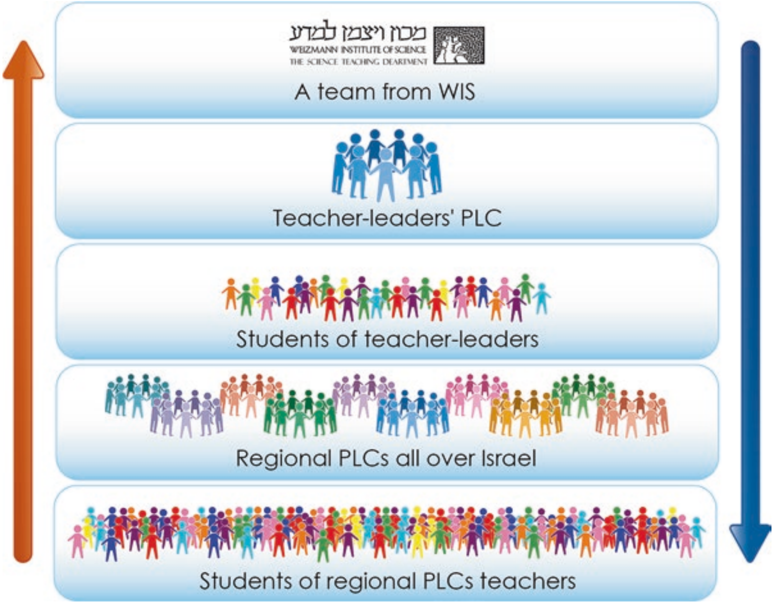


Fig. 3 The "Fan Model" used in the physics teachers' PLCs program

gram operates in a *"Fan Model"* (described in Fig. 3): the teacher-leaders participate in a PLC led by a team from the Weizmann Institute of Science, while they simultaneously lead regional PLCs of high-school physics teachers all over Israel.

The program is based on teacher-leaders' engaging experiences in all contexts of their activity: as learners at teacher-leaders' meetings, as high-school physics teachers, and as leaders of regional PLCs. The teacher-leaders' learning is "evidence-based": They try the new instructional strategies, collect and analyze data about their practice and about the learning of students and of the teachers in the regional PLC, as well as reflect collaboratively on the evidence from classes and from the regional PLCs, regarding learning, teaching, and the leading of PLCs. The design and contents of the program are modified continually according to evidence and insights from classes and from the regional PLCs.

In the 2018 school year there were 25 teacher-leaders in the program and 10 regional PLCs with about 200 high-school physics teachers (about 20% of all high-school physics teachers in Israel), teaching approximately 15,000 students. Each PLC activity, both the teacher-leaders' PLC and regional PLCs, consists of face-to-face meetings lasting 4 h each, twice a month during the school year, totaling 60 h per year.

One of the learner-centered instructional strategies learned in the program was *a collaborative reading assignment*, inspired by Mazur (2014), which was chosen as the context for this study. This assignment is technology-based, and aims at developing students' ability to read and interpret a selected text and to identify its core ideas and concepts in physics, in order to enhance students' conceptual understanding, to promote collaborative learning and ownership of learning physics, and to encourage students to engage in science discourse. The assignment has two parts: in the first part, the students are asked, via a Google Form, to read at home a selected text from the textbook and ask a question about something in the text that is unclear to them. The teacher organizes students' responses in a collaborative Google Sheet. In the second part, also as homework, the students work collaboratively, answer each other's questions, and explain their ideas. In the following physics lesson, the teacher leads a discussion dealing with the main questions that were raised by the students. The entire assignment lasts about a week.

The teacher-leaders experienced the collaborative reading assignment as learners in the teacher-leaders' PLC, as teachers in their own classes, and as leaders of regional PLCs. This assignment was new to all teacher-leaders and fundamentally differed from their traditional teaching methods, pushing them beyond their "comfort zone." They were no longer the main source of knowledge in class and had to engage both their students and the teachers in the regional PLCs in the process of formulating and asking their own questions. In addition, they had to allow the students to make mistakes and to learn from each other. They also needed to learn how to use the new technology of Google Forms and collaborative Google Sheets. In order to implement the collaborative reading assignment successfully, the teacher-leaders had to change their knowledge, their attitudes, and their practice, as well as lead the teachers in the regional PLCs in making similar changes. The implementation of the collaborative reading assignment in the teacher-leaders' practice was affected by a variety of factors that acted as motivators and contributors, or as inhibitors. Identifying these factors is important for better understanding teacher-leaders' PD.

2.2 Methodology

This longitudinal mixed-methods study lasted 3 years (2015–2017). We used case-study methodology that provided us with a systematic, prolonged, and in-depth exploration of complex processes in the teacher-leaders' professional growth within the different contexts of their practice. We focused on the learning as well as the implementation of one instructional strategy, the collaborative reading assignment, as a representative of other learner-centered strategies learned in the program. The *Extended Interconnected Model of Professional Growth* (EIMPG) served as our methodological framework.

2.2.1 Research Questions

1. What changes occurred in teacher-leaders' knowledge, attitudes, and practice, in the context of the collaborative reading assignment?

2. What are the motivators, contributors, and inhibitors to implementing the collaborative reading assignment in teacher-leaders' practice?

2.2.2 Participants

Three teacher-leaders, Dana, Sofia, and Roy, were chosen for the case studies, as representatives of the 25 teacher-leaders in the program. All three are high-school physics teachers, who joined the teacher-leaders' PLC in different years, and differed from each other regarding their background and their previous experience as teacher-leaders. Dana joined the teacher-leaders' PLC in 2014, after 19 years as a teacher, and had no former experience as a teacher-leader. Sofia and Roy joined the teacher-leaders' PLC in 2012. Sofia has been a teacher for 25 years, has been a district teachers' facilitator for 15 years, and had participated in many former PD programs. Roy has been a teacher for 18 years, graduated from a special M.Sc. program designed for excellent physics teachers, and had no former experience as a teacher-leader. Thus, Sofia was a senior teacher and had leadership experience, whereas the other two did not; Roy had research experience, whereas the other two did not.

2.2.3 Data Sources

Data were collected for 3 years (2015–2017) from a variety of sources: video records of six teacher-leaders' PLC meetings during 2015, 13 reflection questionnaires (administered at the end of the teacher-leaders' meeting), 18 interviews conducted with the three teacher-leaders from 2015 to 2017, 15 email correspondences, and six annual portfolios in which the three teacher-leaders reported their experiences. Additional data were obtained from a survey conducted among 165 of all teacher-leaders' students in May 2016 (towards the end of the school year).

2.2.4 Data Analysis

The data related to Dana, Sofia, and Roy in the context of the collaborative reading assignment were gathered from the various sources, and were sorted in chronological order for each of the case studies. Each piece of information (e.g., something that Dana, Sofia, or Roy said in one of the teacher-leaders' meetings, or in an interview, or wrote in their portfolios) was categorized (using Atlas.ti software) according to the contexts of their practice: their classrooms, their school, or the regional PLC that they led. Further categorization was based on the different domains of EIMPG: the External Domain, the Domain of Practice, the Domain of Consequence, and the Personal Domain. For each change in one of the domains, we identified the mediating processes that promoted it: enactment or reflection, and the factors that influenced that change. The enactment and reflection processes were numbered in chronological order, and were presented in a map that we created for each case study based on EIMPG. The maps enabled us to analyze the professional growth of Dana, Sofia, and Roy, and to identify individual as well as similar growth patterns.

The selected data, the categorization, and the EIMPG maps were compared and agreed upon by the four authors. Then the results were validated by four other researchers. Finally, we presented our results to Dana, Sofia, and Roy, and asked for their comments.

3 Results

Dana, Sofia, and Roy underwent a complex, ongoing process of professional growth over 3 years, both as teachers and as PLC leaders. We will first examine the changes in their knowledge, attitudes, and practice, as presented in the EIMPG maps. Then we will consider the factors that motivated, contributed to, or inhibited implementing the collaborative reading assignment in their practice.

3.1 The Changes in Teacher-Leaders' Knowledge, Attitudes, and Practice

3.1.1 Dana's Professional Growth

Dana's EIMPG map is shown in Fig. 4. The mediating processes of enactment and reflection are represented, respectively, as solid and dashed arrows linking the domains. The colors denote the different aspects of Dana's professional experimentations: as a teacher in class, as a teacher-leader in the regional PLC, as a teacher-leader in school, as a member of the teacher-leaders' PLC, and as a user of new technologies for teaching. The numbers on the arrows indicate the chronological order of Dana's enactment or reflection during the 3-year period. The "late reflection" arrow refers to Dana's reflection in a final follow-up interview.

Dana's first experience with the collaborative reading assignment was as a learner in the teacher-leaders' meeting (1 in Fig. 4). In her reflection (2) after that experience, she wrote:

> I don't like this activity. It seems too complicated.

Nevertheless, Dana prepared to enact the assignment in class, and later (28) explained why:

> I knew I would have to implement it in the PLC, so I had to try it in my class first because I feel free to fail there. I can't afford to fail in front of the teachers in the PLC.

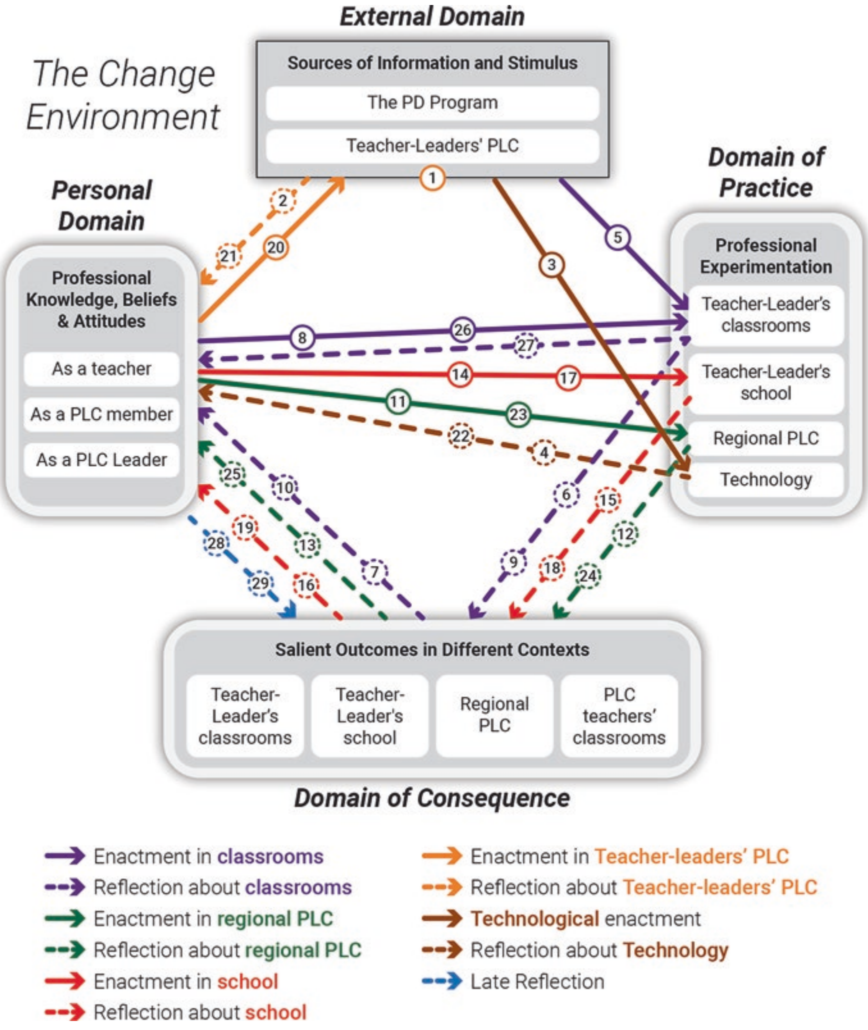


Fig. 4 Dana's EIMPG map

Therefore, Dana created a Google Form, something she had never done before, and practiced this new technology (3 and 4). Then she enacted the assignment in a 12th grade class (5) and interpreted the salient outcomes (6):

> 20 students out of 22 submitted the form, so it was almost all of them. It was hard for them. They said that explaining to their friends made them feel smart.

Dana also reflected on that experience (7):

> The students did it because they had to; I think they didn't really like it. But it is important for me that they will read at home, so even though it wasn't a big success, I achieved my goal.

Dana enacted the assignment again, this time in an 11th grade class (8) and interpreted the outcomes (9):

> In this class it was better. There was an interesting discussion following the homework assignment and they said that it was hard to explain to a friend, but they really tried.

In her reflection (10), Dana referred to the changes that she had undergone:

> It took extra time in class, but it was worth it! They expressed themselves and shared how they felt and what helped them. It was interesting for me to hear them, and I think that this time I chose a more appropriate text and that's why they liked it.

Dana gained new knowledge about the assignment – how to choose an appropriate text, and she changed some of her attitudes, for example "*it's too complicated*" or "*it takes extra time*."

After these experiences with her students, Dana enacted the collaborative reading assignment in her regional PLC (11), interpreted the salient outcomes (12), and reflected on them (13). This experience contributed to the changes in Dana's knowledge and attitudes towards the assignment. She became enthusiastic and discussed it with her school principal, who asked her to share this new activity with all the teachers in school. Dana guided each disciplinary team in school in how to choose an appropriate text and how to implement the collaborative reading assignment, using a Google Form (14). She reflected that the teachers were very interested (15) and that she thinks that this assignment is important for all subjects in school (16). Dana was asked to present the collaborative reading assignment to a delegation from the Ministry of Education who visited her school, as an example of an innovative instructional approach. Dana asked one of her students to help her (17), and was excited about the quality of his presentation (18 and 19):

> This student really understood the meaning of the reading assignment! He told them about the importance of students' independent learning, about the collaboration between the students, and that following this activity, the students felt more comfortable about asking questions. I was really amazed!

In the next teacher-leaders' meeting, Dana shared her impressions from this visit at her school, and reflected on her PD (20 and 21):

> Because I participate in the teacher-leaders' PLC, I feel confident to try these new teaching methods. Otherwise I wouldn't dare.

Following Dana, other teacher-leaders, including Sophia and Roy, presented the collaborative reading assignment in their schools. Further indications regarding the changes in Dana's knowledge, attitudes, and practice were found in her portfolios at the end of that year (July 2015), in the following year (July 2016), and in the follow-up interview in December 2017 (22–29 in Fig. 4). Dana implemented the collaborative reading assignment in her teaching routine, even after more than 2 years, and also modified it to new contexts, e.g., collaborative reading at home as a preparation for lab experiments. Dana reported (in July 2016) that many more students in her school had chosen to major in physics (42 in the coming year, compared to 14 who graduated), and attributed it to changes in her teaching and to her participation in the PLCs' program.

3.1.2 Sofia's Professional Growth

Sofia's EIMPG map is shown in Fig. 5. She experienced the collaborative reading assignment as a learner in the teacher-leaders' meeting (1 and 2 in Fig. 5).

When Sofia enacted the assignment in class (3), she encountered some technical difficulties (4):

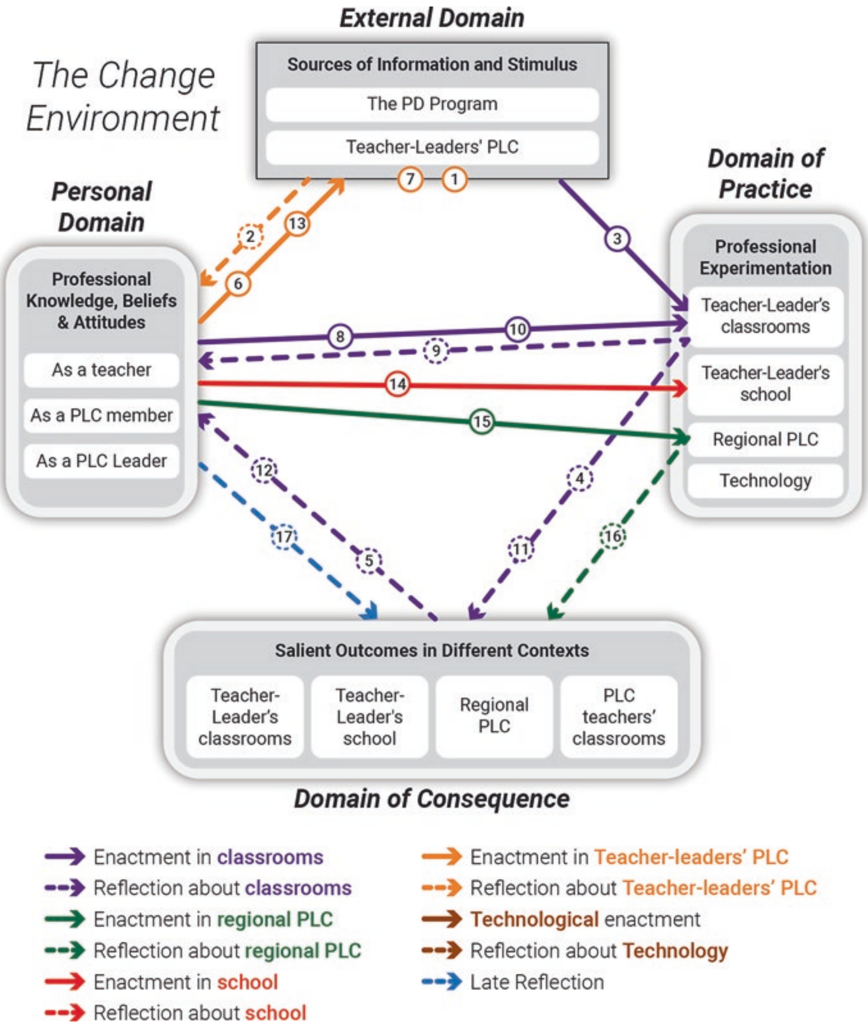


Fig. 5 Sofia's EIMPG map

> I saw a blank Google responses sheet, so I assumed that the students didn't do the assignment. When they insisted that they had done it, I realized that I had sent them the wrong link.

In her reflection (5), she referred to her concerns:

> I apologized and explained to them that I am learning how to use this new tool. I can say it once, but what if it happens again next time?

Sofia asked for help from other teacher-leaders and the leading team (6 and 7), tried the reading assignment twice again in class (8–12), and shared her insights at the next teacher-leaders' meeting (13):

> This time everything went well with the Google Form, but I had another problem. My lessons occur after consecutive days, and we already discussed the students' difficulties in class before the second part of the assignment. So actually in the second part they had no challenges.

Despite the difficulties she had experienced, Sofia promoted the collaborative reading assignment among all the teachers in her school (14). She enacted it once in her regional PLC (15) and reflected on that experience (16):

> I felt that the teachers were not enthusiastic about the reading assignment.

Later on, after December 2015, Sofia did not use the collaborative reading assignment. In the follow-up interview, in December 2017, she explained why:

> Something didn't work out for me in the reading assignment. I felt that I had to force the students to do it and I gave up.

3.1.3 Roy's Professional Growth

Figure 6 shows Roy's EIMPG map. He experienced the collaborative reading assignment as a learner in the teacher-leaders' meeting (1). In his reflection (2) after that experience, he wrote:

> I felt like a student! I looked for things that were not clear to me, and the text became increasingly clearer because of my thorough reading. I really like this assignment, but I am afraid of the technological difficulties.

Roy enacted the collaborative reading assignment in a 12th grade class (3) and interpreted the outcomes (4):

> The students really cooperated in the first part of the assignment, but they had difficulties in the second part – they didn't understand what they should do. I supported them by e-mail.

He reflected on that experience (5):

> It was good experimentation, I really enjoyed it. I felt that in class we could focus on their difficulties, and not waste time on things that they understood well.

In his reflection, Roy also referred to the contribution of the collaborative analysis of students' responses in the teacher-leaders' meeting:

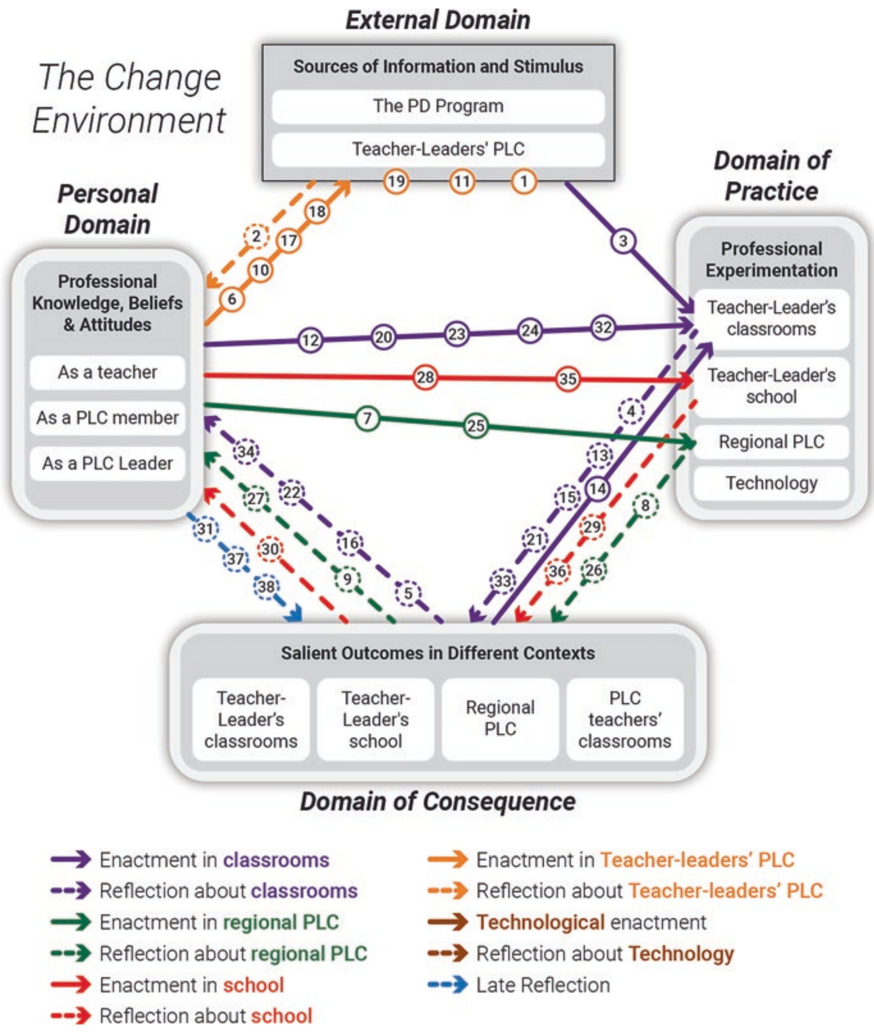


Fig. 6 Roy's EIMPG map

> I was surprised by some of the things that students did not understand, and it felt good to realize that it is not only my students… the fact that most of our students have similar difficulties was reassuring for me. I think this assignment helps us to be more aware of their difficulties.

Roy helped Sofia when she encountered difficulties with the Google Form (6). He enacted the collaborative reading assignment in his regional PLC (7) and reflected on that experience (8 and 9):

> The teachers encountered difficulties. Most of them did not know how to use Google Forms. They said that reading the text made them feel like students, and that this assignment is a

> good strategy to engage students in reading and taking ownership for their learning. However, I am afraid of the technological challenges they face.

Following these experiences in class and in the regional PLC, Roy wrote an e-mail to the leading team and consulted them regarding what he should do in the following lessons (10), and consequently it was discussed in the next teacher-leaders' meeting (11). Subsequently, Roy underwent some sequences of enactment and reflection (12–16), and learned how to choose an appropriate text:

> My mistake at first was that I gave them a long text. I started giving them shorter texts and it worked out much better.

In the teacher-leaders' meeting Roy shared his concerns (17–18):

> What should we do after the reading assignment? How can we address each student's difficulties?

In response, the leading team suggested a summarizing activity based on some of the central questions raised by the students (19). This was followed by many sequences of enactment and reflection in all aspects of Roy's professional experimentation: in his classes, in his school, and in the regional PLC (20–38). He reflected on the reading assignment in his portfolio (July 2015):

> This assignment totally changed my students' reading skills. I noticed that in the lessons after each assignment we could really focus on their questions and address their difficulties.

Roy integrated the collaborative reading assignment into his teaching routine for more than 3 years, and even developed variations and used it in new contexts, for example, collaborative learning when returning an exam.

Dana, Sofia, and Roy's EIMPG maps exhibit ongoing changes in their knowledge, attitudes, and practice. Dana and Roy underwent many significant changes and implemented the collaborative reading assignment in their teaching routine for the long run, whereas Sofia felt insecure and after several unsuccessful experiences gave up.

3.1.4 Implementation in Teacher-Leaders' Classrooms

Further indications of changes in teacher-leaders' practice were obtained by examining the extent to which the collaborative reading assignment was implemented in the classrooms of all teacher-leaders in the program. In May 2016 a survey was conducted among the students of all 25 teacher-leaders (towards the end of the school year, a year after the assignment was introduced in the PLCs). The students were asked how many times during that school year the collaborative reading assignment was used in their physics lessons, and their responses are presented in Fig. 7. As shown, 70% of the students reported that the collaborative reading assignment was used in their physics lessons at least once during that year, and 43% reported that it was used more than twice that year. These findings indicate that most

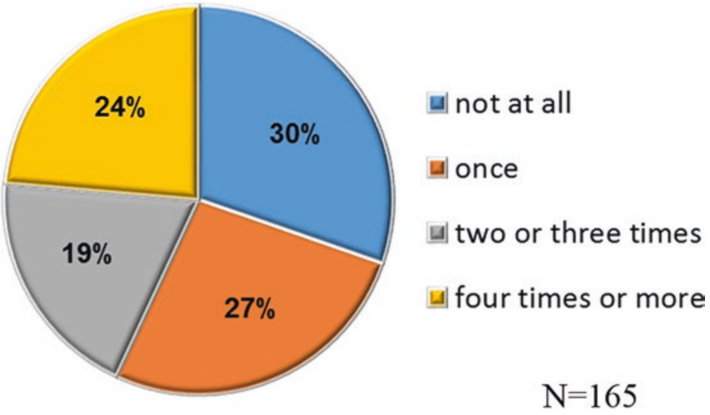


Fig. 7 Implementation of the collaborative reading assignment in teacher-leaders' lessons in the 2016 school year, according to students' reports

of the teacher-leaders integrated the collaborative reading assignment into their teaching routine. However, 30% of the teacher-leaders did not use it at all that year.

The long-term implementation of the collaborative reading assignment in teacher-leaders' classrooms involved a complex, ongoing process of professional growth, as demonstrated in Dana, Sofia, and Roy's EIMPG maps (Figs. 4, 5 and 6). Significant changes took place in Dana and Roy's professional world but to a lesser extent in Sofia's professional world.

We will now consider the factors that acted as motivators, contributors, or inhibitors to the implementation of the collaborative reading assignment in teacher-leaders' practice.

3.2 Motivators, Contributors, and Inhibitors to the Implementation of the Collaborative Reading Assignment in Teacher-Leaders' Practice

Understanding the factors that motivated, contributed to, or inhibited the implementation of the collaborative reading assignment by Dana, Sofia, and Roy might shed light on the factors affecting teacher-leaders' change processes. Dana, Sofia, and Roy participated in the same PD program, shared the same learning environment in the teacher-leaders' PLC with peers who were having similar experiences, and received the needed support from other teacher-leaders and from the leading team. They faced similar challenges in implementing the collaborative reading assignment, e.g., using Google Forms, choosing an appropriate text, planning the lessons in between the two parts of the assignment, tackling unfamiliar situations, motivating the students to cooperate with this new instructional strategy, and motivating the teachers in the regional PLCs to implement the assignment in their classes.

We used the EIMPG as a framework for characterizing the factors that affected the implementation of the collaborative reading assignment in Dana, Sofia and Roy's practice. The categorization was based on the four domains that encompass the teacher-leaders' world: the Personal Domain, the Domain of Practice, the Domain of Consequence, and the External Domain, as well as the contexts of teacher-leaders' PD in each domain. In each of these contexts, we identified a variety of factors that affected the implementation of the collaborative reading assignment, as summarized in Table 1. The different factors are interrelated, of course, and here we demonstrate how they affected Dana, Sofia, and Roy.

Table 1 The factors that acted as motivators, contributors or inhibitors to the implementation of the collaborative reading assignment

Domain	Context	Factors
Personal domain	Professional knowledge	Content Knowledge; Pedagogical Knowledge; Pedagogical Content Knowledge; Technological Knowledge.
	Professional beliefs and attitudes	Towards: collaborative learning; students' ownership of learning physics; the teacher as the main source of knowledge; engaging students in science discourse.
	Personal attributes and circumstances	Experience; personal priorities; commitment; interest.
Domain of practice	Classrooms	An appropriate text for reading; lesson management.
	School	National educational reforms; principal's attitude.
	Regional PLC	An appropriate text for reading; PLC meeting management.
	Technology	Technological challenges
Domain of consequence	Teacher-leader's classrooms	Students' learning; assessment
		Students' attitudes and motivation
	Teacher-leader's school	School teachers' attitudes and motivation
	Regional PLC	PLC teachers' attitudes and motivation
		PLC teachers' experimentations in their classrooms
		Collaborative reflection
External domain	The PD program	The leading team
		The "Fan Model"
		Alternating meetings of teacher-leaders' PLC and regional PLCs
		Academic backing of the Weizma nn Institute of Science
	The teacher-leaders' PLC	Engaging experiences
		"Evidence-based" learning
		Collaborative reflection
		Peer support
		Respectful and non-judgmental environment

3.2.1 Factors in the Personal Domain

Professional Knowledge

Successful implementation of the collaborative reading assignment was based on all aspects of teacher-leaders' knowledge, e.g., Content Knowledge (physics), Pedagogical Knowledge, Pedagogical Content Knowledge, and Technological Knowledge (Koehler & Mishra, 2009; Shulman, 1986, 1987). The teacher-leaders needed to know how to plan the lessons, answer students' questions, and address students' difficulties. They also needed to learn how to use Google Forms and Google Sheets. Dana and Roy had or acquired the professional knowledge needed for successful implementation, whereas for Sofia the needed technological knowledge acted as an inhibitor.

Professional Beliefs and Attitudes

In order to implement the collaborative reading assignment, the teacher-leaders had to change their beliefs regarding the meaning of 'teaching' and 'learning', and to change their attitudes towards collaborative learning, students' ownership of learning physics, the teacher as the main source of knowledge in class, and engaging students in science discourse. These changes in beliefs and attitudes excited Dana and Roy and motivated them to enact the new instructional approach many times. Sofia also reflected (in July 2015) on changes in her attitude as a teacher, in more general contexts:

> Something happened to me as a result of the new strategies I had experienced. I feel much more relaxed in class. When it gets noisy, it doesn't necessarily mean a catastrophe. I don't get stressed when I am not in control 100% of the time for all of the things they're doing. I let them talk, express themselves, ask and discuss more than I ever did.

The findings suggest that the needed changes in teacher-leaders' beliefs and attitudes did not impede implementing the collaborative reading assignment.

Personal Attributes and Circumstances

Each teacher-leader has a different personality, experience, and background. Each teacher-leader also has different priorities, as well as different commitments to the PLCs' program and interest in trying new instructional strategies. Each teacher-leader also operates under different personal circumstances. For example, Sofia was older, and decided to leave the PLCs' program at the end of 2017 (after 6 years), because she became a grandmother, and wanted to spend more time with her family. On the other hand, Dana and Roy were highly motivated to develop professionally and were very committed to the PLCs' program. Roy was eager to try each new instructional idea, and he usually was the first teacher-leader to do so. Dana was usually more cautious before trying new activities in her classes. Such personal factors naturally affected the implementation of the collaborative reading assignment, as well as other new instructional approaches.

3.2.2 Factors in the Domain of Practice

Classrooms

The collaborative reading assignment takes about a week to complete, and consists of two parts as students' homework, and a final discussion in class. The teacher must choose an appropriate text for the assignment and plan the lessons during that week accordingly, so that the issues at the focus of the text that is read will not be discussed in class while the students are working on the assignment at home. This was a big challenge for all three teacher-leaders, and they needed several sequences of enactment in class and reflection in order to choose the appropriate text and timing, and to plan the lessons accordingly. Dana and Roy learned how to do it after several experimentations, whereas Sofia struggled with this challenge and finally gave up.

School

The collaborative reading assignment addresses the objectives of the national educational reform ('meaningful learning') in Israeli high-schools. When Dana, Sofia, and Roy's school principals heard about their experimentations with this new instructional strategy, they encouraged them to share it with all the teachers in school as a good example of innovative teaching. Dana was even asked to present it in front of a delegation from the Ministry of Education. All three teacher-leaders reflected that as a result of the presentation in their schools, they learned that the assignment could be modified for other disciplines. Therefore, the national educational reforms and the principal's attitudes contributed to the implementation of the collaborative reading assignment.

Regional PLC

The main challenge of the teacher-leaders in the regional PLCs was choosing an appropriate text for the teachers' experimentation as learners. Dana reflected that in her regional PLC they chose an inappropriate text, and therefore, the teachers argued about the accuracy of the physics in the text, and consequently, not enough time was left for discussing the advantages of the assignment as an instructional strategy. Sophia and Roy also had time management problems at the PLC meeting. As in the practice in class, the factors of choosing an appropriate text for the assignment and planning the PLC meeting accordingly acted as inhibitors.

Technology

The teacher-leaders needed to learn how to use the new technology of Google Forms and collaborative Google Sheets. Roy, who is technology oriented, had no problems with the new technological tools, and was motivated by the new possibilities these tools had given him in the teaching of physics. Dana needed to practice by herself before using Google Forms with her students for the first time, but she learned how to do it, and indicated that the use of the new technological tools made her feel closer to her students' world. In contrast, for Sofia, the new technology acted as an inhibitor.

3.2.3 Factors in the Domain of Consequence

Teacher-Leaders' Classrooms

The teacher-leaders' perception of salient outcomes after enacting the collaborative reading assignment in their classrooms greatly affected its long-term integration into their practice. The salient outcomes, as the teacher-leaders interpreted them, have two central aspects: (1) students' learning and its assessment, and (2) students' motivation and attitudes.

All three teacher-leaders were concerned about students' learning and its assessment. Sofia reflected on that challenge:

> I am not sure what promoted students' understanding: the reading itself, their friends' explanations, or the class discussion. I also don't know how to assess their responses. What if a student's explanation is wrong? How should I respond?

Roy referred to the positive effect of the assignment on students' learning:

> The reading assignment requires students to read, to pay attention to the important ideas in physics, and to cope with the difficulties.

Another obstacle that the teacher-leaders had to overcome was motivating the students to cooperate in using this new instructional strategy. Roy reflected on that:

> I find it hard to chase after them and force them to complete the assignment.

Students' learning largely acted as a contributor to the implementation of the collaborative reading assignment, whereas students' attitudes and motivation largely inhibited it.

Teacher-Leaders' School

Dana, Sofia, and Roy reflected that the principal was enthusiastic about the collaborative reading assignment as an innovative instructional approach, and that the teachers in their schools were interested in learning how to use this assignment and how to adapt it to their disciplines and needs. For all three teacher-leaders, the attitudes of the principals and schoolteachers were contributing factors.

Regional PLC

The PLC teachers' attitudes towards the collaborative reading assignment and their motivation to enact it in their classes greatly influenced the teacher-leaders. At first, some of the PLCs' teachers did not like the assignment, whereas others were excited about the new technological tools. However, most of the PLCs' teachers enacted the assignment in their classes, as indicated in their annual portfolios, and collaboratively reflected on their experimentations in their PLC meetings. The challenges they had to overcome were similar to those of the teacher-leaders. Dana, Sofia, and Roy reflected that it was interesting for them to hear that the teachers actually enacted the assignment, and even used it in other contexts, e.g., learning from students' mistakes when returning an exam, preparing lab reports and more. The collaborative reflection in the regional PLCs enabled the teacher-leaders to attain a wider perspective about the advantages and the potential of the assignment, exposed them to many optional variations of using it in class, and served as a motivating factor for further implementation.

3.2.4 Factors in the External Domain

The teacher-leaders' PD program and the teacher-leaders' PLC served as the framework for teacher-leaders' learning, and as sources of information, stimulus, and support. We will distinguish between the PD program and its structural characteristics, and the teacher-leaders' PLC as the learning environment.

The PD Program

The professional growth of Dana, Sofia, and Roy was influenced by the PD program that provided the teacher-leaders opportunities to actively investigate their teaching and leading, consistently reflect on their practice and its consequences, and learn from one another.

The Leading Team from the Weizmann Institute of Science, consisting of physics education experts, together with experienced high-school physics teachers, was familiar with the teacher-leaders' professional world, and therefore was able to understand and respond to their needs and difficulties, and designed the contents of the program accordingly.

The "Fan Model", in which the teacher-leaders' PLC has been operating at the Weizmann Institute of Science**,** while the teacher-leaders simultaneously lead the regional PLCs. This model contributed to the teacher-leaders' confidence and enabled them to use their meetings as a model for the regional PLCs meetings.

The Alternating Meetings of the teacher-leaders' PLC and the regional PLCs helped to integrate the teacher-leaders' learning into their practice, both as teachers and as teacher-leaders.

The Academic Backing of the Weizmann Institute of Science enabled a constant access to experts in physics and in physics education, and encouraged the teacher-leaders to implement the new instructional approach and to go beyond their "comfort zone."

The Teacher-Leaders' PLC

Dana, Sofia, and Roy's learning was based on their *engaging experiences* in all contexts of their activity: as learners at teacher-leaders' meetings, as high-school physics teachers, and as leaders of regional PLCs. Their learning was *"evidence-based"*: They tried the collaborative reading assignment in their classrooms, collected and analyzed students' responses, and *reflected collaboratively*. The teacher-leaders' PLC fostered their active, meaningful and collaborative learning, and provided them with ongoing *support from peers* who were having similar experiences, in a *respectful and non-judgmental environment*.

Some of the factors presented in Table 1 had a similar effect on Dana, Sofia, and Roy, e.g., students' attitudes and motivation acted as inhibitors, whereas school principal's attitudes acted as a motivator. However, some of the factors had a different effect on each teacher-leader, e.g., the new technology of Google Forms acted as an inhibitor for Sofia, and as a motivator for Roy. Most of the factors that we identified in the Personal Domain and in the Domain of Consequence are person and context dependent, whereas in the Domain of Practice many factors acted similarly on all three teacher-leaders. In particular, the factors in the External Domain, related to the PD program and the teacher-leaders' PLC, contributed to the implementation of the collaborative reading assignment and supported Dana, Sofia and Roy's professional growth.

4 Discussion

The results of this study show the long-term professional growth of the teacher-leaders, and indicate that significant changes occurred in their knowledge, attitudes, and practice in the context of the collaborative reading assignment. Dana, Sofia, and Roy's EIMPG maps match professional *"growth networks"* of teachers, according to Clarke and Hollingsworth (2002), who distinguished between local or short-term changes and lasting, long-term, teacher growth. Our results add an important aspect: the professional growth of teacher-leaders.

The interactions we found between changes in teacher-leaders' knowledge and changes in their practice demonstrate the construct *Knowtice* (a combination of *knowledge* and *practice*), introduced by Even (2008), which applies to the learning and development of physics teacher-leaders who lead regional PLCs.

The teacher-leaders' professional growth was affected by a variety of factors that acted as motivators, contributors, or inhibitors. These factors are, as Lewthwaite (2006) suggested, person, context, time, and process dependent. Each teacher-leader operates under different personal circumstances and has a different personality, experience, and background. Each teacher-leader also has different views and priorities, as well as different commitments to the PLCs' program and interest in trying new instructional strategies. These personal differences may explain why some factors acted as motivators or contributors for one of the teacher-leaders, whereas they acted as inhibitors for another teacher-leader. Nevertheless, according to our findings, many similar factors affected Dana, Sofia, and Roy. These factors are mainly related to the challenges that the collaborative reading assignment poses, and to the teacher-leaders' PLC and the PD program in general. The factors that we identified as common to Dana, Sofia, and Roy, in the different contexts of their change environment, are of great importance for advancing our understanding of teacher-leaders' PD. Our findings concerning factors in the PD program, e.g., the academic backing, the leading team and its responsive approach, as well as the "evidence-based" approach, are aligned with the literature regarding effective PD programs for teachers (Borko et al., 2010; Eylon et al., 2008; Kallery, 2017; van Driel et al., 2012). Our study adds the aspect of teacher-leaders in a PLCs' program, e.g., the *"Fan Model"* and the alternating meetings of teacher-leaders' PLC and regional PLCs.

The teacher-leaders' PLC fostered active, meaningful, and collaborative learning, and provided the teacher-leaders with ongoing support from peers and from the leading team in a safe and respectful environment. These findings support the literature regarding PLCs as a setting for effective PD (Bolam et al., 2005; Darling-Hammond & Richardson, 2009; Feiman-Nemser, 2001; Vescio & Adams, 2015). Our study contributes the special context of teacher-leaders' PLC as a framework for enhancing the PD of teacher-leaders.

This study addresses the need reported in the literature (Borko et al., 2014; Criswell, Rushton, McDonald, & Gul, 2017; National Academies of Sciences, 2015; York-Barr & Duke, 2004) for research about teacher-leaders' PD programs. Understanding the challenges that physics teacher-leaders face when implementing new instructional strategies can contribute to the design of PD programs for both teachers and teacher-leaders.

Can the cases of Dana, Sofia, and Roy be generalized to other teacher-leaders in the program? Case studies always raise this question. However, this was a 3-year in-depth study with a very rich database, and our findings are in line with the literature regarding science teacher-leaders' PD (Criswell et al., 2017; Lewthwaite, 2006) as well as with our research regarding the teacher-leaders in our program (e.g., Levy, Bagno, Berger, & Eylon, 2018).

Some of the other implications of our study are that since the PLCs program began to operate, the number of high-school students who choose to study physics as a major subject has steadily and significantly increased. Additionally, our program has had a major impact on similar PLCs' programs in chemistry, mathematics, junior high sciences, and others (e.g., Eylon, Bagno, and Scherz, in this volume).

Examples of central issues for future research are to study the factors influencing the recruitment and retention of teacher-leaders as well as the sustainability of such PLCs' programs.

References

Bolam, R., McMahon, A., Stoll, L., Thomas, S., Wallace, M., Greenwood, A., … Smith, M. (2005). *Creating and sustaining effective professional learning communities* (Research report 637). London, UK: DfES and University of Bristol.

Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational Researcher, 33*(8), 3–15.

Borko, H., Jacobs, J., & Koellner, K. (2010). Contemporary approaches to teacher professional development. In E. Baker, B. McGaw, & P. Peterson (Eds.), *International Encyclopedia of Education* (part 7) (3rd ed., pp. 548–555). Oxford, UK: Elsevier.

Borko, H., Koellner, K., & Jacobs, J. (2014). Examining novice teacher-leaders' facilitation of mathematics professional development. *The Journal of Mathematical Behavior, 33*, 149–167.

Clarke, D., & Hollingsworth, H. (2002). Elaborating a model of teacher professional growth. *Teaching and Teacher Education, 18*(8), 947–967.

Criswell, B. A., Rushton, G. T., McDonald, S. P., & Gul, T. (2017). A clearer vision: Creating and evolving a model to support the development of science teacher leaders. *Research in Science Education*, 1–27.

Darling-Hammond, L., & Richardson, N. (2009). Research review/teacher learning: What matters? *Educational Leadership, 66*(5), 46–53.

Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher, 38*(3), 181–199.

DuFour, R. (2004). Schools as learning communities. *Educational Leadership, 61*(8), 6–11.

Etkina, E., Gregorcic, B., & Vokos, S. (2017). Organizing physics teacher professional education around productive habit development: A way to meet reform challenges. *Physical Review Physics Education Research, 13*(1), 010107.

Even, R. (2008). Facing the challenge of educating educators to work with practicing mathematics teachers. In B. Jaworski & T. Wood (Eds.), *The international handbook of mathematics teacher education: The mathematics teacher educator as a developing professional* (pp. 57–73). Rotterdam, The Netherlands: Sense.

Eylon, B. S., & Bagno, E. (1997). Professional development of physics teachers through long-term in-service programs: The Israeli experience. In *AIP conference proceedings* (Vol. 399, p. 299).

Eylon, B. S., & Bagno, E. (2006). Research-design model for professional development of teachers: Designing lessons with physics education research. *Physical Review Special Topics-Physics Education Research, 2*(2), 020106.

Eylon, B. S., Berger, H., & Bagno, E. (2008). An evidence based continuous professional development program on knowledge integration in physics: A study of teachers' collective discourse. *International Journal of Science Education, 30*(5), 619–641.

Feiman-Nemser, S. (2001). From preparation to practice: Designing a continuum to strengthen and sustain teaching. *Teachers College Record, 103*(6), 1013–1055.

Grossman, P., Wineburg, S., & Woolworth, S. (2001). Toward a theory of teacher community. *The Teachers College Record, 103*, 942–1012.

Guskey, T. R. (1986). Staff development and the process of teacher change. *Educational Researcher, 15*(5), 5–12.

Guskey, T. R. (2002). Professional development and teacher change. *Teachers and Teaching, 8*(3), 381–391.

Kallery, M. (2017). Early-years teachers' professional upgrading in science: A long-term Programme. *Research in Science Education*, 1–28.

Klentschy, M. (2008). Developing teacher leaders in science: Attaining and sustaining science reform. *Science Educator, 17*(2), 57.

Koehler, M., & Mishra, P. (2009). What is technological pedagogical content knowledge (TPACK)? *Contemporary Issues in Technology and Teacher Education, 9*(1), 60–70.

Koellner, K., Jacobs, J., & Borko, H. (2011). Mathematics professional development: Critical features for developing leadership skills and building teachers' capacity. *Mathematics Teacher Education and Development, 13*(1), 115–136.

Levy, S., Bagno, E., Berger, H., & Eylon, B. S. (2018). Physics teacher-leaders' learning in a national program of regional professional learning communities. In A. Traxler, Y. Cao, & S. Wolf (Eds.), *Physics education research conference proceedings*. Washington, DC.

Lewthwaite, B. (2006). Constraints and contributors to becoming a science teacher-leader. *Science Education, 90*(2), 331–347.

Little, J. W. (2012). Professional community and professional development in the learning- centered school. In M. Kooy & K. van Veen (Eds.), *Teacher learning that matters: International perspectives* (pp. 22–46). New York, NY: Routledge.

Madsen, A., McKagan, S. B., & Sayre, E. C. (2015). How physics instruction impacts students' beliefs about learning physics: A meta-analysis of 24 studies. *Physical Review Special Topics-Physics Education Research, 11*(1), 010115.

Mazur, E. (2014). *Flat space, deep learning*. Presented in GIREP-MPTL 2014 international conference on teaching/learning physics, July 7–12, Palermo, Italy.

Meltzer, D. E. (2011). Research on the education of physics teachers. *Teacher Education in Physics: Research, Curriculum, and Practice*, 3–14.

Milner-Bolotin, M., Egersdorfer, D., & Vinayagam, M. (2016). Investigating the effect of question-driven pedagogy on the development of physics teacher candidates' pedagogical content knowledge. *Physical Review Physics Education Research, 12*(2), 020128.

National Academies of Sciences, Engineering, and Medicine. (2015). *Science teachers learning: Enhancing opportunities, creating supportive contexts.* Committee on Strengthening Science Education through a Teacher Learning Continuum. Board on Science Education and Teacher Advisory Council, Division of Behavioral and Social Science and Education. Washington, DC: The National Academies Press.

National Research Council. (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

Neumerski, C. M. (2013). Rethinking instructional leadership, a review: What do we know about principal, teacher, and coach instructional leadership, and where should we go from here? *Educational Administration Quarterly, 49*(2), 310–347.

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? *Educational Researcher, 29*(1), 4–15.

Scherr, R. E., Plisch, M., & Goertzen, R. M. (2017). Sustaining physics teacher education coalition programs in physics teacher education. *Physical Review Physics Education Research, 13*(1), 010111.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1–22.

Shulman, L. S. (1997). *Communities of learners and communities of teachers*. Monographs of Mandel Institute.

Timperley, H., Wilson, A., Barrar, H., & Fung, I. (2008). *Teacher professional learning and development*. Wellington, New Zealand: Ministry of Education.

van Driel, J. H., Meirink, J. A., van Veen, K., & Zwart, R. C. (2012). Current trends and missing links in studies on teacher professional development in science education: A review of design features and quality of research. *Studies in Science Education, 48*(2), 129–160.

Vescio, V., & Adams, A. (2015). Chapter 26: Learning in a professional learning community: The challenge evolves. In D. Scott & E. Hargreaves (Eds.), *The Sage handbook of learning*. New York, NY/London, UK: SAGE.

Vescio, V., Ross, D., & Adams, A. (2008). A review of research on the impact of professional learning communities on teaching practice and student learning. *Teaching and Teacher Education, 24*(1), 80–91.

Whitcomb, J., Borko, H., & Liston, D. (2009). Growing talent. *Journal of Teacher Education, 60*(3), 207–212.

York-Barr, J., & Duke, K. (2004). What do we know about teacher leadership? Findings from two decades of scholarship. *Review of Educational Research, 74*(3), 255–316.

Dr. Smadar Levy is a postdoctoral researcher in the Department of Science Teaching at the Weizmann Institute of Science. Her main research explores the continuing professional development of physics teachers and teacher-leaders. Smadar obtained a Master's degree in science education at the Tel-Aviv University (2000), and a Ph.D. in science education at the Weizmann Institute of Science (2017). In her Ph.D., she studied the professional development of physics teacher-leaders in a national program of professional learning communities (PLCs). She has been the coordinator of the PLCs' program in 2012–2016, and since 2018 she is the leader of the program. She is also a teacher-leader in a regional PLC since 2012. Furthermore, Smadar is a physics teacher at Hadarim high school at Hod-Hasharon. She won the Amos De-Shalit Award for excellence in physics teaching (2010), as well as the Israeli Master Teacher Award for excellence in science teaching (2014).

Dr. Esther Bagno is Senior Scientist in the Science Teaching Department at the Weizmann Institute of Science. She has a BSc in Physics and Mathematics from the Bar Ilan University and an MSc and PhD in Science Education from the Weizmann Institute of Science.

Her main areas of practice and research involve high-school students' physics learning and physics teachers' professional development. She developed learning materials for students emphasizing key concepts and principles in physics, and integrated ideas from the learning sciences into the learning and teaching of physics.

She headed the National Center of Physics Teachers in Israel and the Professional Learning Communities (PLCs) of physics teachers spread all over the country. She teaches graduate courses and supervises graduate students.

Dr. Hana Berger is a member of the Department of Science Education at the Weizmann Institute of Science. She obtained a bachelor's degree in physics and mathematics education at the Technion, a Master's degree in computers in education at the Tel-Aviv University and a doctorate in science education at the Weizmann Institute of Science.

Her research thorough the years was in the field of physics teachers' professional development. She is teaching for the 10th year the course "Selected Issues in Physics Education," developed for the Rothschild-Weizmann M.Sc. program for excellent physics teachers. The course is "evidence-based" focusing on students' learning difficulties in various topics, and research based teaching strategies aiming at reducing these difficulties. For the last 7 years she has been a member in the leading team of the Professional Learning Communities (PLCs) of physics teachers spread all over the country. Recently she has joined teams supervising graduate students.

Bat-Sheva Eylon is a Professor in the Science Teaching Department at the Weizmann Institute of Science (WIS) in Israel. She has an MSc in physics from WIS and a PhD in Science and Mathematics Education from UC Berkeley. Her main areas of research lie in the learning and teaching of physics in grades 7–12 and the long-term professional development of teachers and teacher-educators in the areas of physics and other sciences. She has designed and operated a variety of research-based professional development frameworks for teachers such as professional learning communities implemented throughout Israel. The Knowledge Integration Perspective on Teaching and Learning, developed and researched with peers, has served as a conceptual framework for many of these activities, as well as for curriculum development programs and technological innovations. Currently she chairs the Vidactics program and co-chairs the Personalized Teaching and Learning (PeTeL) initiative as well as the Rothschild-Weizmann Program for Excellence in Science Teaching. Bat-Sheva is a Fellow of the AAAS. In 2015 she received the EMET prize in education.

Discussion: Teacher Professional Development in the Era of Change

Dragana Martinovic and Marina Milner-Bolotin

1 Introduction

This discussion is based on the analysis of three chapters in this book section: Waldman and Blonder's, *A Sense of Community in a Professional Learning Community of Chemistry Teachers: A Study of an Online Platform for Group Communication*, Brandes, Ben-David Kolikant, and Beeri's, *From Practice to Practical: Computer Science Teachers Teaching Teachers*, and Levy, Bagno, Berger, and Eylon's, *Motivators, Contributors, and Inhibitors to Physics Teacher-Leaders' Professional Development in a Program of Professional Learning Communities*. All three chapters address the issues around professional development (PD) of Israeli science teachers in view of the recent changes in secondary chemistry, physics, and computer science curricula. To these analyses, we add the discussion on the research findings and insights from Canada and elsewhere, regarding the PD practices for mathematics, finding both the common themes and important differences.

Waldman and Blonder researched how an online professional learning community (PLC) (Lave & Wenger, 1991) of 14 selected secondary school chemistry teachers, can become a vehicle for their ongoing PD. These Lead Teachers would then become the link between the science education research community, represented by the authors of the paper, and the local schools. This PLC was created in order to further support PD of chemistry teachers through regional PLCs. To connect and communicate, the Lead Teachers used WhatsApp smartphone application, which created a space for learning and socializing independently of the boundaries

---

D. Martinovic (✉)
Faculty of Education, University of Windsor, Windsor, ON, Canada
e-mail: dragana@uwindsor.ca

M. Milner-Bolotin
Department of Curriculum and Pedagogy, Faculty of Education,
University of British Columbia, Vancouver, BC, Canada
e-mail: marina.milner-bolotin@ubc.ca

Y. Ben-David Kolikant et al. (eds.), *STEM Teachers and Teaching in the Digital Era*, https://doi.org/10.1007/978-3-030-29396-3_10

of time and place. The Lead Teachers met over WhatsApp between the bi-weekly face-to-face meetings with five facilitators. The face-to-face meetings addressed the aspects of building the PLC, learning and teaching chemistry (e.g., students' conceptual difficulties, effective pedagogical approaches, technical issues faced by chemistry teachers), and the curriculum.

In their analysis of the WhatsApp discourse over the two academic years, Waldman and Blonder used a Sense of Community framework (McMillan & Chavis, 1986) as "a feeling that members have of belonging, a feeling that members matter to one another and to the group, and a shared faith that members' needs will be met through their commitment to be together" (p. 9). As a result of their study, Waldman and Blonder concluded that WhatsApp allowed for creation of all four elements of the Sense of Community framework: membership—personal relatedness, influence, integration and fulfillment of needs and reinforcement, and shared emotional connection. Nevertheless, the Lead Teachers found it challenging to go against an apparent norm in social networking—to talk only about positives and share success stories, while ignoring the challenges or failing to provide critical feedback. The authors were concerned that while the technology afforded unlimited access and flexible use, social norms, such as this one, could potentially prevent all voices to be heard and different experiences to be shared. Identifying the limitations of virtual learning communities was an important contribution of this chapter to research on the role of professional communities on teacher professional development and practice (Vescio, Ross, & Adams, 2008). However, the authors could not provide clear suggestions about *how educators can overcome this limitation and use social media to successfully promote open and uncensored sharing of their experiences.*

Brandes et al.'s chapter describes a PD scenario, in which the leading secondary school computer science teachers participated in a course especially designed to help them switch from procedural to object-oriented programming. PD is particularly important for computer science teaching, as teachers are often asked to teach programming languages that they have not been previously exposed to. In the course run by the university staff, the 12 Lead Teachers were prepared to organize workshops for their peers on this new curriculum topic. The course consisted of nine 6-h long meetings in which the Lead Teachers learned content and pedagogy envisioned by the curriculum developers, and received resources (e.g., Power Point Presentations) and support in drafting the workshop presentations. When planning and conducting the workshops, these teachers could have relied on: (a) their own classroom experience, (b) knowledge and skills gained during the course, (c) other Lead Teachers in the group, and (d) the university team of facilitators.

The authors analyzed five workshops conducted by the Lead Teachers. In comparison to the Power Point resources created by the curriculum developers, the Power Point presentations prepared by the Lead Teachers had fewer slides, were simplified and more focused on the practical hints and content, than on the pedagogy. Brandes et al. interpreted this unexpected outcome as filtering based on the Lead Teachers' own teaching experiences. This chapter prompted us to ask the following questions: *What knowledge is valued by the practitioners? To what extent the centrally given PD for Lead Teachers become individualized and filtered in its delivery to peers in the field?*

In their chapter, Levy et al. focus on a PD of high-school physics Lead Teacher participating in a national PLC program and identify the factors that influenced their knowledge, attitudes, and practice. As theoretical framework, the researchers used the Interconnected Model of Professional Growth (Clarke & Hollingsworth, 2002), which looks at one's change from the perspective of the Personal Domain, the Domain of Practice, the Domain of Consequence, and the External Domain. Levy et al. were able to add to this framework more nuances across all four domains, as their project used a rather complex "Fan Model" of PD. Namely, Lead Teachers received PD from a team from the Weizmann Institute of Science, while teaching students and presenting at staff meetings in their schools, and facilitating PLCs of physics teachers across Israel.

For this chapter, Levy et al. chose to present the cases of three Lead Teachers who experienced changes across all domains and sub-domains of professional growth. For Lead Teachers it was important that they had continuous access to their own classrooms as spaces to experiment with ideas and activities they encountered during the PD. The support of their school principals contributed to Lead Teachers' confidence and allowed them to present at staff meetings, which ultimately transferred into more cross-curricular implementations. The PD involved use of social media (e.g., Google Forms and collaborative Google Sheets), which improved technology skills of both Lead Teachers and the PLC participants, and supported collaborative learning. The researchers recommended that "teachers' PD be based on authentic evidence from classes and on collaborative examination of students' works in order to encourage teachers to consider changes in their practice." The emphasis on evidence from classes and research in designing PD resonates with our own work (Milner-Bolotin, 2018).

It is important to emphasize the key difference in teaching chemistry or physics compared to teaching computer science, which was also reflected in the two different approaches to teacher PD described in the chapters. While the chemistry and physics curricula have been relatively stable, the curriculum in computer science has undergone significant changes in recent years. As a result, the Pedagogical Content Knowledge (PCK) (Shulman, 1986) of chemistry and physics teachers has changed much less than the PCK of computer science teachers, who are much more pressured to continuously update it. Consequently, the PD of computer science teachers was more focused on updating teachers' subject-specific PCK then the PD of chemistry or physics teachers, as can be seen from these three chapters.

2 Our Musings about Teacher PD in the Era of Change

One way to support education reforms in STEM disciplines is to provide science and mathematics Lead Teachers dedicated time and resources to collaborate and effectively support their peers (Wellcome Trust, 2013). Such approach was implemented in Israel and Canada (see chapters "Teacher Knowledge in the Era of Change", "Professional Learning Communities of Science Teachers: Theoretical and Practical Perspectives", "A Sense of Community in a Professional Learning Community of Chemistry Teachers: A Study of an Online Platform for Group Communication", "From Practice to Practical: Computer Science Teachers Teaching Teachers", and "Motivators, Contributors, and Inhibitors to Physics Teacher-Leaders' Professional Development in a Program of Professional Learning Communities") and elsewhere (e.g., US, Australia, Finland, etc.). When we understand teacher leadership as a form of collective leadership in which teachers develop expertise by working collaboratively (Boles & Troen, 1994), then different PD models emerge. For example, after selected Lead Teachers learn within their own support group, they could individually lead their peer groups (as in the three chapters), or serve on their schools' Learning Leadership Teams (as in Martinovic & Horn-Olivito's chapter).

This two-stage model has the main characteristics of the "Train the Trainer" approach and provides a cost-effective PD (as a small number of educators receive training delivered centrally and then they train their colleagues, see Fig. 1). Pancucci (2007) describes it as:

> a "quick and dirty" solution to a board's training and [PD] needs. Teachers also appear to favour workshops that target "tricks-of-the-trade" as is the case in many Train the Trainer workshops [7]–[18]. A major limitation of the Train the Trainer model is that it does not provide the time for teachers to assimilate the knowledge, skills, philosophies, and concepts that are essential for a deep understanding and appropriate application of the training provided. In essence, a higher order in-depth application of the concepts and skills is not learned through the Train the Trainer training. Consequently, it is possible that the lead teachers are not prepared to deliver the training to their school colleagues because they are unable to understand the needs of their team and/or because they do not have a deep understanding of the material. (p. 15)

The expectation of the Train the Trainer model is that Lead Teachers/trainers pass onto their peers the information their received during their PD sessions. Rosen (2017) noted that such a transmission model of PD was indeed followed by the Teacher Leaders in her study, prompting her to suggest "that a more constructivist and reflective learning approach would help teachers truly learn, change, and improve instructional practice (Fullan, 2006)" (p. 11). In the three studies discussed here, the Lead Teachers received training offered by the PD facilitators in multiple sessions (for 2 years, chemistry Lead Teachers met every second week; computer science Lead Teachers had nine training sessions; and Lead physics Teachers met twice a month during three school years). So, we could assume that the Lead Teachers were well informed about the (new) curriculum content and pedagogy.

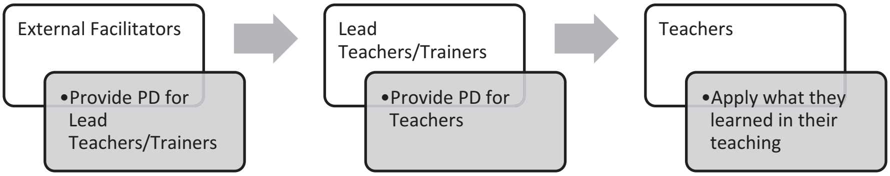


Fig. 1 The sequential structure of the Train the Trainer model

Still, in the case of Brandes et al. study, Lead Teachers decided to provide their peers with "tricks-of-the-trade" (Pancucci, 2007), which they perceived their peers needing most.

Here, we recall Hargreaves and Fullan's (2012) advice that although the informal sharing of practice is important, even more important is to create among educators a collaborative culture that offers opportunities for both informal and formal learning. Formal learning, when it happens in a system of shared purpose and values in teaching, fosters critical thinking and honest dialogue, "[with understanding] that open discussions and temporary disagreements will not threaten continuing relationships" (p. 113).

Waldman and Blonder found that the online conversations among the chemistry Lead Teachers, even after 2 years, did not produce an adequate level of the critical thinking and dialogue proposed by Hargreaves and Fullan (2012). While it appeared that the PLC had a sense of community (McMillan & Chavis, 1986), their public communication consisted of sharing positive news, experiences, and acknowledgements. The researchers were puzzled, as they expected that "…stories and words of others [would] open up less defensive, more honest dialogue" (Bell, 2010, p. 10). However, to their surprise, it was not the case. To understand why it happened, would require further investigation.

2.1 Understanding Teacher Learning

Teacher professional learning is not a straightforward process. The three Israeli studies describe different implementations of what we originally considered as closely related to the Train the Trainer PD model. In this section, we further analyse these approaches using the three conceptions of teacher learning defined by Cochran-Smith and Lytle (1999): knowledge-*for*-practice, knowledge-*of*-practice, and knowledge-*as*-practice. By doing so, we try to understand the dominant ideas behind these Israeli initiatives, and to compare and contrast them beyond the surface differences in their organizational arrangements.

2.1.1 Knowledge-*for*-Practice Approach

The first approach defined by Cochran-Smith and Lytle (1999) is based on extending teachers' "knowledge-*for*-practice"—a model in which the outside experts (e.g., university researchers; school board facilitators) organize PD sessions based on the accepted knowledge about how the subject is learned and taught.

> A heavy emphasis here is on the need for teachers to learn additional and richer content information as well as new bundles of strategies and skills…This approach maintains clear distinctions between expert and novice teachers as well as between very competent teachers and those who, albeit experienced, simply do not know enough content or methods to teach effectively. (Cochran-Smith & Lytle, 1999, p. 258).

However, in our view, this approach is problematic, as it considers teachers as recipients of knowledge. Waldman and Blonder's Lead chemistry Teachers were selected by an official from the Israeli Ministry of Education and received PD from researchers at the Weizmann Institute of Science. Brandes, Ben-David Kolikant, and Beeri's Lead computer science Teachers were "experienced teachers with a good reputation, who already knew basic [object-oriented programming]" and who volunteered to receive PD from professors at the Hebrew University of Jerusalem. Lead Teachers in Levy et al.'s chapter were experienced physics teachers who "joined" the lead teachers' PLC even before the study commenced. Math Leads in Martinovic and Horn-Olivito's study were elementary school teachers selected for this position by their principals; they received PD offered by the school board facilitators. Thus, all four projects demonstrate conditions of the knowledge-*for*-practice PD model, in terms of externally provided PD of Lead Teachers, and more or less institutionalized distinction between the Lead Teachers and their peers. As their Ontario counterparts, Israeli Lead Teachers were obliged "to deepen their [subject] knowledge through professional learning, to apply this learning in the classroom and to share strategies for learning with other teachers in their school" (Ontario Ministry of Education, 2016, p. 5) or region.

Cochran-Smith and Lytle (1999) also put this approach in the context of school/curriculum reforms:

> In many school change efforts animated by knowledge-*for*-practice, teachers are presumed to learn from ongoing training and coaching provided by officially certified 'trainers' in a particular model. The preferred contexts in which this training and coaching occur are the course, workshop, or whole-school training project sponsored by a university, school district, or educational publisher. (pp. 261–262)

Such, knowledge-*for*-practice—in essence, a transmission-based PD model—still prevails in education systems, although these four examples from Israel and Ontario show that it may have evolved into a Train the Trainer model (Pancucci, 2007), as its more cost-effective version. However, how do these four projects align with the other two teacher learning models described by Cochran-Smith and Lytle (1999)?

2.1.2 Knowledge-*as*-Practice Approach

Since for all four projects, the PD was "Facilitated [in] teacher groups, dyads composed of more and less experienced teachers, teacher communities, and other kinds of collaborative arrangements that support teachers' working together to reflect in and on practice" (Cochran-Smith & Lytle, 1999, p. 263), they also have characteristics of the knowledge-*in*-practice model of teacher learning. This more constructivist approach, acknowledges that while teaching, educators apply prior knowledge and experience, which they adapt and revise, thus creating a new knowledge. Furthermore, learning is considered a social activity that happens continuously over time, rather than only at discrete moments (e.g., during PD sessions). For our discussion, it is especially relevant that knowledge-*in*-practice approach carries "an image of teaching as wise action in the midst of uncertain and changing situations"(p. 266). The Lead Teachers in all four projects applied new learning in their classrooms and shared what they know with their PLCs or school colleagues. Dana, in Levy et al.'s study admitted that she draws confidence from her PD for trying "new teaching methods [with her students]. Otherwise [she] wouldn't dare." Knowing that she will have to use the same activity with her PLC teachers, she "had to try it in [her] class first because [she felt] free to fail there," but not "in front of the teachers in the PLC."

Lead computer science Teachers in Brandes et al.'s study conducted workshops for their PLCs in which they focused on practical knowledge and filtered their knowledge from practice. This suggests that their Lead Teachers used a knowledge-*in*-practice approach, as the one "That sells well" (Shmuel; Brandes et al.) with other teachers. This is not surprising since Cochran-Smith and Lytle (1999) write,

> The idea that there is knowledge in practice is congruent with the increasing acknowledgment in the educational community that much formal research has little bearing on the most immediate and central problems of education. Increasingly, there are serious questions about the usefulness for teaching and learning of a paradigm that divides knowledge generation from knowledge application. (p. 263)

Brandes et al.'s concept of "[from] 'practice to practical'…supports the claim that teachers have unique viewpoints, agendas and beliefs according to which they filter and shape what and how they teach their peers (Abell, Appleton, & Hanuscin, 2010)" (Brandes, Ben-David Kolikant, & Beeri,…). It seems to us that both this project (unintentionally) and Martinovic and Horn-Olivito's project (intentionally) incorporated aspects of the knowledge-*in*-practice model, as the goal of the latter was to emancipate teachers as "holders of contextualized and practitioner knowledge...and to equip them with confidence to teach, to conduct research, and to lead." Reflection and inquiry are the main tools for nurturing knowledge-*in*-practice (Cochran-Smith & Lytle, 1999). Prior to the Mathematics Leadership Learning Projects, many educators in Martinovic and Horn-Olivito's study went through a series of collaborative inquires supported by the university researchers. This equipped them with skills for reflective practice, which "is congruent with knowledge-*in*-practice" (Cochran-Smith & Lytle, 1999, p. 269).

The aspects of a knowledge-*in*-practice model were clearly present in Levy et al.'s study. The researchers emphasized it as an "evidence-based" learning. The Lead physics Teachers first tried in their classrooms the activity which was flashed out during their PD sessions, and after analyzing their students' responses and reactions, "reflected collaboratively." Throughout the project, the Lead Teachers (and their PLCs' participant teachers) went through the cycles of enactments and reflections (both individual and collaborative), thus gaining "a wider perspective about the advantages and the potential of the assignment[s]." This prompts us to ask *if and how were personal reflections different from the collaborative ones and which were more valued by the teachers*.

For Waldman and Blonder, Sense of Community framework was used as a lens for their consequent analysis, so their PLC facilitators' responsibility was to support community development and to provide encouraging feedback to their members. Nevertheless, the authors did not clarify if and how their PLC facilitators "push[ed other PLC members] to question their own assumptions and reconsider the bases of actions or beliefs" (Cochran-Smith & Lytle, 1999, p. 271). This, however, is a crucial element of knowledge-*in*-practice PD, where facilitators "use cases or reflections or inquiries …to provide the social and intellectual contexts in which … teachers can probe the knowledge embedded in the wise teaching decisions of others and/or can deepen their own knowledge and their own abilities to make wise decisions in the classroom." (p. 272). So, although the authors saw that the "WhatsApp discourse dealt with asking for help, clarification, and consultation regarding chemistry, chemistry teaching, and management," it seems that the discourse lacked the details needed for a knowledge-*in*-practice PD. Since the WhatsApp allows for sharing multimedia attachments, maybe sharing video clips of teaching situations would inspire deeper discussions and reflections around the sources of teachers' actions, reasoning, and decisions? The PLC members could then be asked to describe how these videos and discussions with others affected their own practice.

2.1.3 Knowledge-*of*-Practice Approach

This third type of teacher learning connects teachers and their knowledge "to larger political and social agendas" (Cochran-Smith & Lytle, 1999, p. 274), which may be particularly relevant in the context of educational reforms. The knowledge-*of*-practice means "that practice is more than practical, that inquiry is more than an artful rendering of teachers' practical knowledge" (p. 274) and "that teachers learn by challenging their own assumptions; identifying salient issues of practice; posing problems; studying their own students, classrooms, and schools; constructing and reconstructing curriculum; and taking on roles of leadership and activism in efforts to transform classrooms, schools, and societies" (p. 278).

Cochran-Smith and Lytle consider that the PLC model provides opportunities for teachers to share with peers knowledge-*of*-practice which is generated when "teachers treat their own classrooms and schools as sites for intentional investigation at the same time that they treat the knowledge and theory produced by others as generative material for interrogation and interpretation" (p. 250). This approach "always involves some kind of systematic collection, analysis, and interpretation of data" (p. 279), which we saw in Levy et al.'s and Martinovic and Horn-Olivito's study, but not in the other two discussed chapters. In Levy et al.'s project, "evidence-based" continuous professional learning of the Lead Teachers and their PLCs' participants provided opportunities for such critical analyses of the curriculum and the change leadership. Cochran-Smith and Lytle (1999) are precise when saying that the discourse here goes beyond informal chats and phrases of encouragement, which were predominant in Waldman and Blonder's PLC. It would be very interesting for us to learn how the Lead chemistry Teachers worked within their regional PLCs, as there we could find other aspects of teacher learning.

2.2 The Roles of Lead Teachers in the PD Efforts

Is there something that Waldman and Blonder's, Brandes et al.'s, and Lily et al.'s facilitators or Lead Teachers could have done differently? We consider the initiatives in which the Lead Teachers are selected based on heterogeneous criteria such as teaching performance, knowledge of content, experience, availability, and willingness, and are expected to lead PD of communities of their peers and ultimately bring change in the system. It is important to identify ways in which to support these Lead Teachers in achieving such expectations. We recall that Cooper et al. (2016) found it critical for teacher leaders to possess substantial knowledge of instructional leadership and strategies for leading change. Borko, Koellner, and Jacobs (2014) even defined knowledge of mathematics leaders as, *Mathematical Knowledge for Professional Development*, which encompasses.

> specialized content knowledge, pedagogical content knowledge, and learning community knowledge [which] go beyond and look different than the knowledge [of] a typical mathematics classroom teacher... [Also,] PD leaders should be knowledgeable about how to work productively with adult learners, and construct environments for teachers to collaborate about relevant topics. (p.165)

Cooper et al. (2016) and Borko et al. (2014) suggest that Teacher Leaders should have specific skills, which is also a prominent idea in Ferguson and Danielson's (2015) call to differentiate PD based on teachers' needs, while honouring teachers' autonomy as professionals. From this perspective, PD of Lead Teachers should be different from the PD that they would carry out with other teachers (see Fig. 2).

During the PD sessions/workshops for teachers, Brandes et al.'s Lead computer science Teachers modeled teaching of different curriculum units. These Lead Teachers highly valued the knowledge they developed through teaching and in comparison considered inadequate "all other professional development [courses], [led by] a professor or someone from the industry, or someone who knows programming" (Shmuel; Brandes et al.). It may also be that these Lead Teachers could do more than to present "exercises, solutions and content examples that 'worked'" in their own classrooms (Brandes et al.). Although the teachers in their audience may

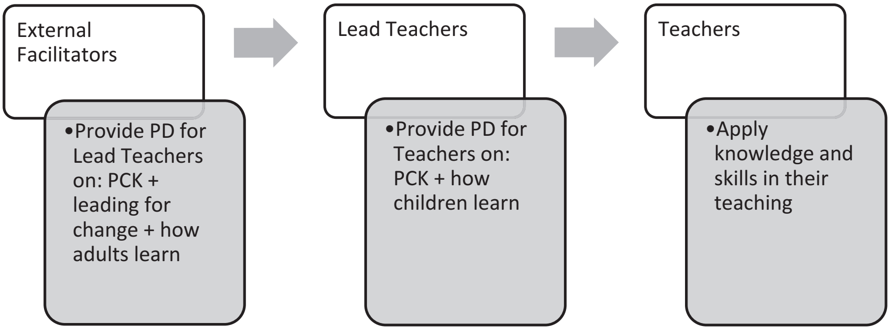


Fig. 2 A differentiated and sequential PD model

"favour workshops that target 'tricks-of-the-trade'" (Pancucci, 2007, p. 15), they could benefit from more "modeling" that is "encourag[ing] reflection on teaching rather than replication of teaching (Elliott et al., 2009). This would require an acknowledgment that any lesson is to some degree an experiment; and that even a 'best practice' will require much fine-tuning when manifested with particular students on a particular day in a particular classroom" (Margolis & Doring, 2012, p. 878). Instead, the Lead Teachers using "Practicality … as a filter" (Brandes et al.) seem to have "[equated] practice with that which is practical (Britzman, 1991), or useful, immediate, functional, and concerned with the everyday" (Cochran-Smith & Lytle, 1999, p. 290). That left the university research team perplexed, as it made a clear distinction between the Lead Teachers' knowledge-*as*-practice and the researchers' knowledge-*for*-practice.

Rosen (2017) suggests that

> If teacher leaders' roles were constructed more as a facilitator of learning than an expert transmitter of information" their "role could be a powerful impetus for learning experiences that take a 'knowledge in practice' (Cochran-Smith & Lytle, 1999) approach to inquiry and reflection, an approach that generates new knowledge and encourages improved practice through long-term and substantive change. (p. 11).

In other words, facilitators of PD for Lead Teachers should expect and indeed support the idea that the PD for teachers should be different. Similarly, the Lead Teachers should be prepared to deliver PD that is different from the PD that they participated in. We recall that Steven Katz (2017) uses a term "knowing your class," which means that educators need to adapt their "lessons" based on who is in their class. In the facilitators' class are Lead Teachers, in the Teacher Leaders' class are teachers, and in the teachers' class are students. Since these classes are different in terms of PCK, role, and age, the "lessons" must be different too, which is the crux of the differentiated PD model in Fig. 2.

3 Conclusions

In this discussion chapter, we mused over our reading of the three section chapters using the three conceptions of teacher learning (Cochran-Smith & Lytle, 1999) and ideas from the more recent literature on teacher PLC and leadership. We made parallels between the PD models in Waldman and Blonder's, Brandes et al.'s, and Levy et al.'s studies and the Train the Trainer model, and by doing so revised the sequential PD model (see Fig. 1) to include a differentiated PD (see Fig. 2). Further considerations of Waldman and Blonder's and Brandes et al.'s results revealed that during application, the sequential PD model may get disrupted in different ways. One such disruption happened when the Lead computer science Teachers started filtering what is "passed-on" to teachers (and we can expect that similar filtering happens in what teachers deliver to students). One can look at this as a regression—indeed, it is hard to ensure the fidelity of messages that reach students in such interventions—thus questioning if the planned outcomes of such an initiative were reached. Or, one can see in what was observed an affirmation of educator's agency—these Lead Teachers used their professional judgement to deliver what they considered was best for their audience, and the teachers will likely do the same as a result of what Little (1990) describes as, "The classroom [overwhelming] other sources of information" (p. 527).

Waldman and Blonder's Lead Teachers engaged in the predominantly positive and supportive exchanges, while Brandes et al.'s Lead Teachers tried to be overly helpful to their PLC audiences. Both were identified as problematic by the authors. As Little (1990) warned,

> Patterns of interaction that support mutual assistance or routine sharing may account well for maintaining a certain level of work-force stability, teacher satisfaction, and a performance "floor." They seem less likely, however, to account for high rates of innovation or for high levels of collective commitment to specific curricular or instructional policies. They seem less likely to force teachers' collective confrontation with the school's fundamental purposes or with the implications of the pattern of practices that have accumulated over time. (p. 531)

Another disruption happens with introduction of technology in the professional learning process. Waldman and Blonder's Lead Teachers did not talk about instances of failure, but that does not mean that they did not discuss them within smaller circles that did not include the facilitators. Indeed, technology allows for parallel conversations to remain hidden. Also, the silences may include "[withholding] one's knowledge, methods and materials in order to preserve their individual reputations" (Benson, 2011, p. 182), the issue well-recognized in situations when collaboration is promoted in the system that is based on the competitive rules.

Levy et al.'s Lead physics Teachers used technology in the assignment for their students and for the regional PLCs' participants. The technology did not work for all as expected; for some it was a motivator and for others an inhibitor of learning. We also found very interesting that one of the Lead Teachers, Roy, whom the authors described as "technology oriented," feared of "the technological difficulties" during the implementation/enactment phase. In his reflection, post the teacher PLC's experience, he stated, "The teachers encountered difficulties. Most of them did not know how to use Google Forms. …I am afraid of the technological challenges they face." While we do not know (after reading the chapter) if Roy (and other Lead Teachers) noticed the same frustration with technology among their peers and students, it is indicative that one third of the regional PLCs' participants did not use this assignment and close to one third used it only once. At this point, we can just speculate that "technology difficulties" were an inhibiting factor for a number of teachers, resulting in avoidance. We are also curious if Levy et al. noticed in Roy's (or other Lead Teachers') PLCs, elements of 'filtering' of what is passed onto teachers participants? Indeed, Roy's concern about "the technological challenges [teacher may] face," probably affected his actions within the regional PLC he facilitated.

The authors of the three chapters discussed here described their efforts in organizing PD of educators in the era of ongoing educational reforms. The challenges and successes they recorded were anticipated in the literature and they should be acknowledged for their “explicit attempts to encompass multiple conceptions or dimensions of collegiality…, to discriminate among these various forms of collegiality, and to trace their apparent consequences” (Little, 1990, p. 531).

References

Abell, S. K., Appleton, K., & Hanuscin, D. L. (2010). *Designing and teaching the elementary science methods course*. New York, NY: Routledge.

Bell, L. A. (2010). *Storytelling for social justice: Connecting narrative and the arts in antiracist teaching*. New York, NY: Routledge.

Benson, K. (2011). *Teacher collaboration in context: professional learning communities in an era of standardization and accountability.* (Ph.D.), Arizona State University, Tempe, AZ. Retrieved from https://repository.asu.edu/attachments/56839/content/Benson_asu_0010E_10806.pdf

Boles, K. C., & Troen, V. (1994). *Teacher leadership in a professional development school*. Paper presented at the American Education Research Association Annual Meeting.

Borko, H., Koellner, K., & Jacobs, J. (2014). Examining novice teacher leaders’ facilitation of mathematics professional development. *Journal of Mathematical Behavior, 33*, 149–167.

Britzman, D. (1991). *Practice makes practice: A critical study of learning to teach*. Albany, NY: State University of NY Press.

Clarke, D., & Hollingsworth, H. (2002). Elaborating a model of teacher professional growth. *Teaching and Teacher Education, 18*, 947–967.

Cochran-Smith, M., & Lytle, S. L. (1999). Relationships of knowledge and practice: Teacher learning in communities. *Review of Research in Education, 24*, 249–305. https://doi.org/10.2307/1167272

Cooper, K. S., Stanulis, R. N., Brondyk, S. K., Hamilton, E. R., Macaluso, M., & Meier, J. A. (2016). The teacher leadership process: Attempting change within embedded systems. *Educational Change, 17*, 85–113.

Elliott, R., Kazemi, E., Lesseig, K., Mumme, J., Carroll, C., & Kelley-Petersen, M. (2009). Conceptualizing the work of leading mathematical tasks in professional development. *Journal of Teacher Education, 60*(4), 364–379. https://doi.org/10.1177/0022487109341150

Ferguson, R. F., & Danielson, C. (2015). How framework for teaching and tripod 7Cs evidence distinguish key components of effective teaching. In T. Kane, K. A. Kerr, & R. C. Pianta (Eds.), *Designing teacher evaluation systems: New guidance from the measures of effective teaching project* (pp. 98–143). San Francisco, CA: Jossey-Bass.

Fullan, M. (2006). *The new meaning of educational change* (4th ed.). New York, NY: Teachers College.

Hargreaves, A., & Fullan, M. (2012). *Professional capital: Transforming teaching in every school*. New York, NY: Teachers College Columbia University.

Katz, S. (2017). *Networked learning: How together “can” be better*. Retrieved from https://drive.google.com/file/d/0BzzEDT0DXGrsZk42MXk0NUFuYzQ/view

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, UK: Cambridge University Press.

Little, J. W. (1990). The persistence of privacy: Autonomy and initiative in teachers’ professional relations. *Teachers College Record, 91*(4), 509–536.

Margolis, J., & Doring, A. (2012). The fundamental dilemma of teacher leader-facilitated professional development: Do as I (kind of) say, not as I (sort of) do. *Educational Administration Quarterly, 48*(5), 859–882.

McMillan, D. W., & Chavis, D. M. (1986). Sense of community: A definition and theory. *Journal of Community Psychology, 14*(1), 6–23.

Milner-Bolotin, M. (2018). Evidence-based research in STEM teacher education: From theory to practice. *Frontiers in Education: STEM Education, October, 3*, 14. https://doi.org/10.3389/feduc.2018.00092

Ontario Ministry of Education. (2016). *Ontario's renewed mathematics strategy*. Toronto, Canada: Ontario Government Retrieved from http://www.edu.gov.on.ca/eng/policyfunding/memos/april2016/dm_math_strategy.pdf

Pancucci, S. S. (2007). Train the trainer: The bricks in the learning community scaffold of professional development. *International Journal of Social Sciences, 2*(1), 14–21.

Rosen, M. L. (2017). Teacher leaders as professional development providers: Factors driving teacher learning opportunities. *Journal of Education and Human Development, 6*(2), 1–15.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.

Vescio, V., Ross, D., & Adams, A. (2008). A review of research on the impact of professional learning communities on teaching practice and student learning. *Teaching and Teacher Education, 24*, 80–91.

Wellcome Trust. (2013). *The deployment of science and Maths leaders in primary schools*. Retrieved from London, UK: https://wellcome.ac.uk/sites/default/files/wtp056231_1.pdf

Dragana Martinovic is a Professor of Mathematics Education at University of Windsor, where she leads the Human Development Technologies Research Group. Dragana is a Fellow of the Fields Institute for Research in Mathematical Sciences and a Co-Director of the Fields Centre for Mathematics Education. She is a recipient of the Excellence in Mentoring Award at University of Windsor. In her research, Dr. Martinovic explores ways in which technology can improve teaching and learning outcomes, and the digital literacy skills needed for a successful learner and worker of the twenty-first century. She is dedicated to supporting teacher-led research and providing opportunities for all involved in education to collaboratively work towards increasing student engagement, success, and love for learning mathematics. Dragana is on the Executive for the Mathematics Knowledge Network, hosted by the Fields Centre for Mathematics Education. She co-chairs the Mathematics Leadership Community of Practice (since 2016) and the *Fields Cognitive Science Network for Empirical Study of Mathematics and How it is Learned*, and is a founding and current co-editor of the Springer book series, *Mathematics Education in the Digital Era*.

Marina Milner-Bolotin is an Associate Professor in science education in the Faculty of Education at the University of British Columbia, Vancouver, Canada. She holds a M.Sc. in theoretical physics from the Kharkov National University in Ukraine. She also holds M.A. and Ph.D. degrees in mathematics and science education from the University of Texas at Austin in 2001. At UT Austin, she investigated how project based instruction in physics courses for future elementary teachers affected their interest in science and their ability to do and teach science. She specializes in science and mathematics education and science outreach. She studies how technology can be used in teacher education to prepare mathematics and science teachers who will be able to engage twenty-first century students in meaningful learning. Her work has appeared in international peer-reviewed research journals, scientific books, conference proceedings, seminars, and workshops. Since 1993, she has been teaching science and mathematics in Israel, USA, China, and Canada to elementary students to university undergraduates in science programs, and to pre-service and in-service teachers. She has led many professional development activities for science in-service and pre-service teachers and university faculty. She is an author of an introductory physics textbook used by thousands of students. Before joining UBC, she was faculty member at Ryerson University in Toronto, Ontario. She has received numerous research and teaching awards and served on the Executive Board of Canadian and International science education associations. To learn more about her research and publications, visit her web site at: http://blogs.ubc.ca/mmilner/.

Part IV
Emergent STEM Teaching Possibilities in the Era of Educational Technologies

Deliberate Pedagogical Thinking with Technology in STEM Teacher Education

Marina Milner-Bolotin

1 Introduction

Technology affects all aspects of our lives: from an unprecedented information access to the ever-increasing time we spend with digital devices, to *how* we communicate, and, *how* and *what* we learn. With these rapid developments, we are yet to appreciate the full scope of technology's political, economic, and societal impact. Technology has wiped out entire industries, such as an analog photography or video rentals, replacing them with their digital counterparts we could barely imagine a decade ago. Novel technologies have already replaced thousands of manufacturing workers, subway train operators, or even grocery stores cashiers. Technology will inevitably challenge humans' status quo in more traditional fields, making us wonder if teachers will benefit from or become the next victims of the technological revolution (Muller, 2018a).

It is time to ask two critical questions relevant to the twenty-first century educators: How our society, our values, and views of education have evolved as the result of these developments? What are their implications on the twenty-first century teacher education? For example, an unprecedented access to information, poses a serous challenge to both the public sphere and the educational realm. As Neil Postman (1985) stated more than 30 years ago, echoing the famous Aldous Huxley's dystopian 1931 novel *Brave New World*, having access to a sea of information while lacking the capacity to examine it critically, can be as dangerous as being deprived of the information to begin with. Postman pointed out that most of the information we receive nowadays does not lead to meaningful actions on our part either because we perceive it bearing little relevance to our immediate lives, or because we are incapable of acting upon it. This metaphorical "drowning" in the sea of irrelevant

---

M. Milner-Bolotin (✉)
Department of Curriculum and Pedagogy, Faculty of Education,
University of British Columbia, Vancouver, BC, Canada
e-mail: marina.milner-bolotin@ubc.ca

Y. Ben-David Kolikant et al. (eds.), *STEM Teachers and Teaching in the Digital Era*, https://doi.org/10.1007/978-3-030-29396-3_11

information is even more relevant today. This also applies to novel educational technologies. The exponential growth of technological innovations unsupported by teachers' pedagogical knowledge prevents these technologies from making a difference to student learning. This is a perpetual problem plaguing contemporary secondary Science, Technology, Engineering and Mathematics (STEM) education (Cuban, Kirkpatrick, & Peck, 2001; Milner-Bolotin, 2016a). In this chapter, by STEM education we mean both the teaching and learning of distinct secondary STEM subjects, and the education that breaks traditional STEM silos and challenges learners to integrate mathematics, sciences, engineering and technology knowledge to solve complex problems.

Modern educational resources play a big role in contemporary STEM education. Among these free or low-cost resources are: (a) educational video channels (Khan, 2013; Milner-Bolotin, 2018c; Muller, 2018b); (b) online K-12 and university courses (Massachusetts Institute of Technology, 2018); (c) research-based computer simulations (Wieman, Adams, Loeblein, & Perkins, 2010); (d) data collection and analysis tools (Maciel, 2015), and (e) formative assessment tools (Chien, Chang, & Chang, 2015). However, STEM educators are yet to understand how to use these tools to support student meaningful engagement with different STEM subjects as well as their integration to solve everyday life problems. The results of the recent international STEM assessments and educational research both in the K-12 and post-secondary contexts indicate that the availability of these tools is insufficient to significantly affect the quality of student STEM learning (Let's Talk Science, 2016; OECD, 2016a). North American students have access to a wide range of educational tools, and yet many of them choose to either not enroll or drop out of STEM courses (Chachashvili-Bolotin, Milner-Bolotin, & Lissitsa, 2016; DeCoito, 2016; Let's Talk Science, 2013; OECD, 2016b, 2016c).

It has become clear that to improve student STEM learning in addition to having access to technologies, teachers have to embrace research-informed technology-enhanced pedagogies (Deslauriers, Schelew, & Wieman, 2011; Levin & Tsybulsky, 2017; Milner-Bolotin, 2017; Schmidt et al., 2009). Thus, teachers' attitudes and beliefs about technology and the goals of STEM learning are crucial for reforming their pedagogical practices (Jones & Leagon, 2014). Therefore, to improve how the twenty-first century students engage with STEM, teacher educators and researchers have to help future teachers acquire the pedagogical skills needed for effective technology integration (Schmid et al., 2014). Until we do that, as Larry Cuban mentioned at the dawn of this millennium, available educational technologies will remain expensive "oversold and underused gadgets" that make very little impact on STEM learning experiences of our students (Cuban, 2001).

In order to break the vicious cycle of having unprecedented access to technology and yet making meager progress in student learning, educators have to start with examining the role of technology in teacher education. Paraphrasing a famous Dewey's quote, one can say: If we educate today's teachers as we did it in the yesterday, we rob them (and their future students) of tomorrow. The goal of the next section is to consider twenty-first century alterative education of future teachers.

2 Technology in STEM Teacher Education: Closing the Theory-Practice Gap

In order to examine the role of technology in preparing STEM teachers who are capable and willing to use it to promote student learning, we begin by posing a series of questions, such as: What do we mean by *effective use* of educational technologies by STEM teachers and students? As Martinovic and her colleagues point out, "intelligent partnership with technology" in learning mathematics is based on the new principles in learning and doing mathematics (Martinovic, 2015; Martinovic, Muller, & Buteau, 2013). According to the authors, *technology as a partner* should encourage student mathematical creativity and intellectual independence, thus helping them develop their own understanding of the mathematical principles, rather than being exposed to these principles, as the product of the intellectual efforts of others. The same applies to other STEM fields. New tools open opportunities to authentic inquiries that were impossible to carry out earlier, but teachers must be prepared and willing to seize these opportunities (Milner-Bolotin, 2012). The goal of these technology-enabled investigations is not only to acquire new understandings, but also to learn first-hand about how STEM knowledge is acquired, tested, and validated. It is not surprising, that the focus on the process and nature of different STEM fields and on the communication of ideas is a prominent feature of current educational reforms (British Columbia Ministry of Education, 2015; Quinn, 2011).

Technology should also affect how we prepare future STEM teachers (Etkina, 2010; Milner-Bolotin, 2018a). Then, what does it mean to prepare teachers who are willing and capable of using technology effectively (Milner-Bolotin, 2016b, 2018a)? Does a presence of technology in a secondary STEM classroom guarantee that students will be engaged and inspired to study STEM at college (Chachashvili-Bolotin et al., 2016)? How do we guarantee that novel technologies do not reinforce "doing old things in old ways with new tools" (Manny-Ikan & Dagan, 2011)? How do we inspire teachers not only to do "old things in new ways" but also to do "new things in new ways"? (Manny-Ikan, Berger Tikochinski, & Bashan, 2013). They call for the technology-inspired transformation of STEM education that adds value to the learning process through engaging learners in collaborative knowledge construction supported by peers, teachers, and technology.

What is the relevant knowledge for teaching contemporary STEM teachers need to acquire in order to use technology to successfully facilitate student learning (Koehler & Mishra, 2015; Milner-Bolotin, 2016a)? Is the knowledge of content, content-specific pedagogies, and relevant technologies enough to become a successful teacher? What else should be considered as essential knowledge for successful twenty-first century teaching? How do we support the growth of this knowledge during teacher education and teachers' entire careers? How do we prepare STEM teachers who will view their teaching licence as the license to continue learning and embracing novel currently non-existing and even unimaginable technologies during their teaching careers? How do we empower teachers to deliberately use these tools to support student meaningful STEM learning as opposed to using technology as an artificial add-on (Milner-Bolotin, 2016a)? What are context-specific aspects of effective technology use in various subjects, grade levels, and contexts? And finally, the most important question: What are the theoretical underpinnings of successful technology-enhanced learning environments and what are their implications for teacher education (Jonassen & Land, 2012)? This paper examines some of the implications of the education research on preparing secondary STEM teachers.

The case for examining the role of modern technologies in STEM teacher education is interesting for at least six reasons. *First*, secondary STEM educators are continuously "bombarded" by new curricula, new educational demands, and new technologies (British Columbia Ministry of Education, 2015; NRC, 2013).

Second, focussing on secondary STEM teacher-candidates (TCs) allows teacher educators and researchers to influence the future of STEM education. While it might be difficult to change the pedagogies, attitudes, and educational goals of experienced teachers, one can affect how the next generation of teachers is being educated and what knowledge, values, and attitudes TCs acquire during their own education.

Third, the majority of TCs in the teacher education programs today are grown up in the Internet age. Thus, TCs are familiar with some of the modern technologies as social media users. This removes the initial barrier for educational technology use. However, it does not mean that TCs know how to use technology for educational purposes. While they might be digital natives in a general sense (Prensky, 2001a, 2001b), they are often novices in the educational uses of technology beyond the social media.

Fourth, STEM teachers are more likely than the teachers of other subjects to have positive experiences with technology (Martinovic & Zhang, 2012). In general, as most of STEM teachers in Canada as in many other countries have earned a Bachelor of Science or Bachelor of Engineering degrees before being admitted to a teacher education program (in mathematics, TCs can earn a Bachelor of Arts in Mathematics as well). During their undergraduate studies, many STEM TCs were required to undertake various laboratory courses and some TCs even took part in undergraduate research projects that gave them an opportunity to engage with modern technologies as a research tool first hand.

Fifth, STEM subjects are closely connected to modern technologies, thus many students who will take STEM courses at advanced levels will be interested in technology. Therefore, STEM TCs have a direct motivation to experience these tools in their teacher education program.

Sixth, since 1980s in North America, undergraduate STEM programs have led the way in utilizing evidence-based pedagogies and modern educational technologies in their introductory courses (Hake, 1998). Many Faculties of Science and Applied Science have implemented some innovative pedagogies in their Bachelor programs, such as Peer Instruction (Lasry, Mazur, & Watkins, 2008; Mazur, 2009; McQueen, Shields, Finnegan, Higham, & Simmen, 2014), technology-enhanced collaborative learning (Denny, 2010; Kalman, Milner-Bolotin, & Antimirova, 2010; Wieman, Rieger, & Heiner, 2014), inquiry-based learning (Deslauriers et al., 2011; Milner-Bolotin, 2012), etc. For example, at the University of British Columbia, for almost a decade Carl Wieman Science Education Imitative has been focussed on implemented educational research into undergraduate mathematics and science courses

(Carl Wieman Science Education Initiative at the University of British Columbia, 2012). Thus, many of STEM TCs have experienced some kind of technology-enhanced pedagogies in their undergraduate STEM studies. The following section sheds light on the knowledge that STEM TCs should acquire in order to be able to implement modern technology to engage school students in meaningful learning.

3 Deliberate Pedagogical Thinking with Technology Framework for Teacher Knowledge Growth

This chapter suggests a novel way of examining STEM teachers' knowledge for teaching and its growth – Deliberate Pedagogical Thinking with Technology (DPTwT) framework (Milner-Bolotin, 2016a). Each one of the words in the framework's name bears a special meaning while the order of words is also important. The emphasis on *deliberate* in DPTwT stresses that student learning should be the ultimate driver in choosing tools or pedagogies. Teachers should be deliberate about the pedagogies they employ. At the same time, pedagogy should precede technology. Technology is a pedagogical aid in the hands of a teacher who supports student learning.

To illustrate how this framework can be used to connect education research and practice, the following section will present three examples of technology-enhanced pedagogies inspired by the DPTwT framework. These pedagogies have been implemented in STEM methods courses to support the development of TCs' practical knowledge for technology-enhanced STEM teaching at the University of British Columbia during the last 6 years. The effects of these pedagogies on TCs have been studied extensively (Milner-Bolotin, 2016b; Milner-Bolotin, Egersdorfer, & Vinayagam, 2016; Milner-Bolotin, Fisher, & MacDonald, 2013). However, before providing these specific examples, it is important to outline the DPTwT framework.

DPTwT theoretical framework (see Fig. 1) (Milner-Bolotin, 2016a, 2016b) combines the original Shulman's (1986) Pedagogical Content Knowledge (PCK) framework and its technological counterpart, Technological Pedagogical and Content

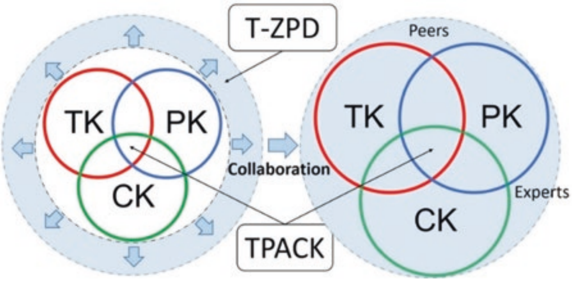


Fig. 1 DPTwT framework focuses on the growth of teacher knowledge through peer collaboration in a community of practice. It extends the original TPACK framework through applying Vygotsky's ZPD concept to teacher professional development

Knowledge (TPACK) framework by Koehler and Mishra (2015), with Vygotsky's Zone of Proximal Development (ZPD) concept (1978). It focuses on knowledge growth as it helps educators to think about not only what the teacher already knows, but what she can learn through collaboration with peers or through the interaction with technological tools. While this framework in not STEM specific, it is especially relevant for considering STEM teachers' knowledge growth.

According to Vygotsky, ZPD is the difference between what a learner can do while working alone versus what they can do when supported by others. This support can be the guidance by the teacher or a collaboration with peers.

While the original paper by Shulman (1986) that introduced PCK, contained the phrase "Knowledge *growth* in teaching" (the emphasis is added) in its title, it focussed on outlining the present state of teacher's knowledge for teaching (the static knowledge) as opposed to the process of knowledge acquisition or teacher's ability to acquire new knowledge. Shulman also did not describe the role of teacher collaboration and participation in the professional educational communities, also referred to as communities of practice (Wenger, 1998), in the process of formation of their knowledge for teaching. The TPACK framework suggested by Koehler and Mishra a decade later did focus on technology, but once again, did not look at the teachers' pedagogical growth as a result of their collaboration and engagement within innovative technology-enhanced learning environments (Harris, Mishra, & Koehler, 2009). In addition, the TPACK framework does not consider technology as a catalyst for the growth of teachers' professional knowledge. It focuses on technology as a pedagogical tool that can help teachers enhance students' learning experiences. This is understandable, as at the time when the TPACK was proposed, technology did not play as significant a role in teachers' communities of practice as it does now. Nowadays, technology is not only a tool for teachers to teach with, but also a tool to learn and grow with. This is as true for teacher education as it is for teacher practice.

The major contribution of the proposed DPTwT framework is in inspiring educators to focus on the *growth of teachers' knowledge of technology-enhanced pedagogies* as a result of collaboration with peers in a face-to-face or virtual community of practice. This framework is applicable to both pre- and in-service teachers and is useful in designing, implementing, and evaluating technology-enhanced learning environments.

The following section provides examples of how DPTwT can be used to design technology-enhanced learning environments in secondary STEM Methods Courses at a Teacher Education Program at the University of British Columbia.

4 Three Examples of DPTwT Framework in Action in STEM Teacher Education

This chapter describes three examples of technology-enabled pedagogies grounded in the DPTwT theoretical framework. All these technology-enhanced pedagogies were implemented in STEM methods courses. The implications of modeling deliberate use of technology in STEM teacher education where TCs are invited to experience these technologies as learners and reflect on them as future teachers are also considered below. Finally, we comment on the value of providing these collaborative technology-enhanced experiences for STEM TCs during their teacher education.

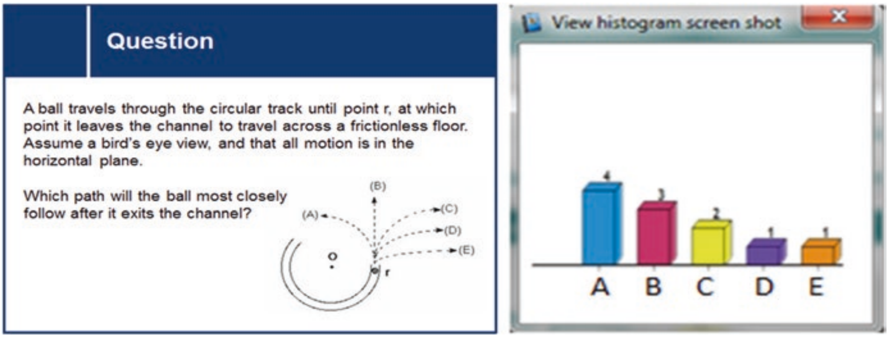
The first example describes how PeerWise technology (a web-based system developed at the University of Auckland) coupled with Peer Instruction pedagogy (Fagen, Crouch, & Mazur, 2002; Mazur, 1997a) can be used to support TCs in STEM methods courses in learning how to ask effective conceptual questions and promote learner collaboration (Denny, 2010, 2018; Milner-Bolotin et al., 2016). The second example considers how Collaborative Learning Annotation System (CLAS) (Dang, 2018) can be used to support teacher-candidates in developing reflective practice and learning to provide and accept constructive pedagogical feedback (Milner-Bolotin, 2018b). The third example outlines how technology can be used to support TCs in collaboratively designing educational resources for the entire STEM education community. In one of the methods course assignments, TCs were asked to design short educational videos of STEM experiments that are relevant to K-12 curriculum (Milner-Bolotin, 2018c; Milner-Bolotin & Milner, 2017). They shared these videos with each other first and then made them available to the entire educational community and the general public via a YouTube channel (Milner-Bolotin, 2018c). In all these examples technology was used deliberately to promote TCs' collaboration, reflective practice, and comfort level with purposeful use of educational technologies to promote STEM learning. The design of these learning environments was grounded in the DPTwT framework that guided teacher educators through providing opportunities for TCs to grow their TPACK thanks to technology-supported peer collaboration.

4.1 PeerWise and Peer Instruction in STEM Teacher Education

4.1.1 Peer Instruction

Peer Instruction (PI) is a widely used pedagogical strategy in contemporary STEM education (Mazur, 1997b). It increases student engagement during teacher-centered lessons, encourages students to check their understanding and to collaborate with peers. PI incorporates classroom response systems (clickers), various personal electronic devices, or flashcards to engage students in answering specially designed conceptual multiple-choice questions that target student difficulties by using common misconceptions as distractors (Fig. 2) (Lasry, 2008; Mazur, 1997b).

After displaying initial responses to the question, the students are invited to discuss their answers with the peers. This is followed by a repeated individual voting and an all-class discussion. PI in STEM classrooms results in increased student engagement, frequent and continuous feedback to both students and the instructor regarding the level of student understanding, and improved student learning (Hake,



Question

A ball travels through the circular track until point r, at which point it leaves the channel to travel across a frictionless floor. Assume a bird's eye view, and that all motion is in the horizontal plane.

Which path will the ball most closely follow after it exits the channel?

Fig. 2 A conceptual physics multiple-choice question from Force Concept Inventory and the distribution of TCs' responses (Hestenes, Wells, & Swackhamer, 1992)

1998). The increased availability of emergent technologies has contributed towards promotion of interactive engagement pedagogies, and specifically PI, in K-12 classrooms (Lasry, 2008; Milner-Bolotin, Kotlicki, & Rieger, 2007; Wieman et al., 2010). However, there is extensive research evidence demonstrating that PI success lies not in the technology itself, but in instructor's PCK (Smith, Wood, Krauter, & Knight, 2011). Thus in order to prepare TCs for successful implementation of PI and other interactive engagement pedagogies in their classrooms, these pedagogies should be introduced in teacher education, so TCs can experience them as students (Milner-Bolotin et al., 2013).

The key element of the DPTwT framework is the focus on the growth of teacher knowledge through collaboration and with the aid of technology. PI is based on learner collaboration and uses technology to promote it through instantaneous feedback. PI has been found effective in teacher education (Kolikant, 2010; Milner-Bolotin et al., 2013). However, from the teaching perspective, it is important that TCs can collaborate on designing pedagogically effective conceptual questions that they can implement during PI in their own classrooms. The growth of TCs' knowledge comes from their collaboration with peers on writing conceptual STEM questions, on their responding to their peers' questions, and on their mutual feedback and support. Having a technology that can support this process, would facilitate the growth of TCs' knowledge. One of these new technologies that can be especially useful in this process is, PeerWise (Denny, 2018). It seems to be well-suited for putting PI into action in STEM teacher education.

4.1.2 PeerWise Online Collaborative System

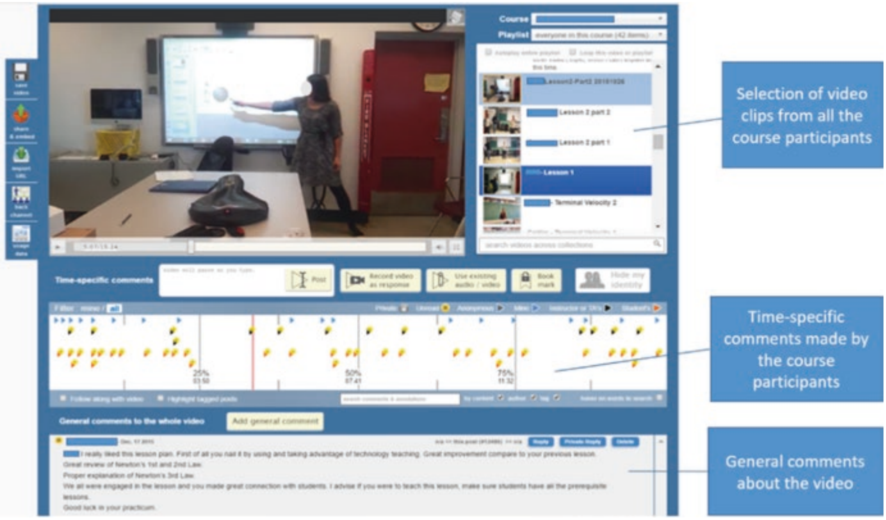
PeerWise is an online platform for hosting student-authored multiple-choice questions and promoting student engagement through online collaboration (Denny, 2018). The use of PeerWise and PI fits perfectly in STEM teacher education as this technology offers a user friendly collaborative platform for TCs to develop their

PCK and become comfortable with technology use in STEM education. PeerWise allows students to answer, rate, and comment on multiple-choice questions created by their peers (Milner-Bolotin, 2014). PeerWise also has a game-like aspect as participants rate each other's contributions thus earning credibility and respect points. PeerWise has mainly been implemented in large undergraduate science courses, with results indicating that student engagement through question-creation produces positive learning outcomes (Bates, Galloway, Riise, & Homer, 2014; Hardy et al., 2014). For the last 4 years, we have been using PeerWise in STEM teacher education to promote TCs collaboration on designing conceptual multiple-choice questions. The use of PeerWise in STEM teacher education is grounded in the DPTwT theoretical framework because this technology is used to provide TCs with an opportunity to collaborate and support each other while designing educational resources they will be using in their practicum and post-graduation. Thus, the goal of PeerWise use in STEM teacher education is to expand TCs' PCK and TPACK through online and face-to-face collaboration and mutual support. Moreover, as PeerWise is free, TCs can use it in their own classrooms during the practicum and after graduation.

4.2 Collaborative Learning Annotation System in STEM Teacher Education

Collaborative Learning Annotation System (CLAS) is a freely available online media player and an online collaborative platform (Dang, 2018). CLAS allows uploading, sharing, and commenting on videos stored in it, while making both time-specific and general comments (see Fig. 3) (Milner-Bolotin, 2018b). The participants can respond to specific comments and create discussion threads focused on specific features of their videos. The instructor has a full control of who has access to the videos, so the videos can be shared with the entire class or with a sub-set of students. The comments made by the instructor or by the students can be made either private or public. Most importantly, CLAS is compatible with the videos recorded using smartphones, iPads or tablets, already in the hands of TCs, thus, no additional video-recording equipment is needed to use CLAS.

We have been using CLAS since 2013 in our secondary STEM methods courses. Usually these are small courses – up to 25 TCs, most of whom have already completed their B.Sc. degree (some of the TCs are enrolled in a concurrent teacher education program). As part of the course requirements, TCs are asked to teach at least four 10-min mini-lessons to three to five of their peers and provide feedback to at least four mini-lessons taught by their peers. Due to the short length of the course (36 h in total), the mini-lessons are limited in length and frequency. To use the time more efficiently, the students are split into four to five groups, thus TCs are asked to teach their mini-lessons to three to five of their peers. Consequently, four to five mini-lessons can run simultaneously. Then the recordings of the mini-lessons are



[redacted] Dec. 17 2015

[redacted] I really liked this lesson plan. First of all you nail it by using and taking advantage of technology teaching. Great improvement compare to your previous lesson.
Great review of Newton's 1st and 2nd Law.
Proper explanation of Newton's 3rd Law.
We all were engaged in the lesson and you made great connection with students. I advise if you were to teach this lesson, make sure students have all the prerequisite lessons.
Good luck in your practicum.

Selection of video clips from all the course participants

Time-specific comments made by the course participants

General comments about the video

Fig. 3 A screen shot of CLAS interface. By clicking on different icons in the time-specific comments area, one can read and respond to all the comments pertinent to different parts of the video. To find more about the system visit: http://ets.educ.ubc.ca/clas/ (Milner-Bolotin, 2018b)

uploaded on CLAS and all TCs are invited to watch and comment on them. The course instructor and the course Teaching Assistant (a graduate student who is often a STEM teacher) provide detailed feedback for them. This online feedback is essential, as the instructor or the Teaching Assistant cannot be physically present while videotaping all the mini-lessons. The online feedback from these more experienced educators is aimed at supporting all TCs in their growth, as well as to model various feedback strategies. This is part of the cognitive apprenticeship approach implemented in many of our methods courses, in which instructors model teaching practices they want TCs to adopt in their own teaching (Collins, Brown, & Newman, 1989; Lave, 1990; Milner-Bolotin, 2018b).

There are a number of reasons for incorporating CLAS in STEM methods courses. First, CLAS assignment encourages TCs to reflect on their own teaching through watching the recordings of their mini-lessons. Doing this encourages TCs to reflect on their teaching strategies, communication skills, and the use of educational technologies. It also allows TCs to identify their strengths and weaknesses, such as their general communication skills, ability to use a board effectively, to engage students, to model problem solving strategies, and respond to students' questions. Thus, CLAS models the use of technology as a tool for teacher collaboration, reflection, and professional growth.

Second, TCs provide constructive feedback on their peers' mini-lessons, which inspires them to learn from and with peers. Since during the lessons some of them act as students, TCs learn to think of potential student difficulties, required prior knowledge, and experiences of the lesson.

Third, CLAS activity inspires TCs to come up with suggestions for improvement, as well as respond to peer feedback. This is a crucial quality for becoming an effective teacher (Etkina, 2010; Milner-Bolotin, 2018b). As a result, many TCs decide to re-teach the same mini-lesson while using alternative teaching strategies. This is an additional CLAS benefit for STEM methods courses: TCs learn that good teaching is not about creating a "perfect" lesson from the get-go, but continually improving it. Thus, such usage of CLAS inspires growth mindset in TCs (Dweck, 2016).

Fourth, reflecting on their and their peers' mini-lessons through CLAS taught TCs the difference between Failure and failure (Milner-Bolotin, 2018a). Winston Churchill once said "Success is not final, failure is not fatal: it is the courage to continue that counts." Learning any new skill inevitably consists of many small failures. In order to prevent them turning into a big Failure (giving up on learning), learners have to be supported in the process through continuous constructive feedback. The learners also have to be given time to master the skill and to be encouraged to try it multiple times. The same should apply to learning how to teach and learn STEM. CLAS –supported pedagogy encourages TCs to reflect on their teaching, receive constructive feedback and try it again. It also models how they can support their future students when they experience failures in STEM learning.

Fifth, the positive feedback on their teaching allows TCs to see their own progress and eventually build their confidence and self-efficacy as STEM teachers. Passionate but less experienced teachers are often their own worst critics, so receiving positive and constructive support from peers and the instructor, is a much needed boost for improving TCs' confidence in their ability to become successful educators.

We have described TCs' feedback on the CLAS implementation elsewhere (Milner-Bolotin, 2018b). While our courses are relatively small and TCs' feedback could not be generalized, TCs engagement with CLAS was overwhelmingly positive. Here it is important to emphasize that the use of CLAS in STEM teacher education was inspired by the DPTwT framework and the growth mindset (Dweck, 2016). CLAS technology was used deliberately to enable and support teacher growth through reflection, peer collaboration, and active participation in the community of practice.

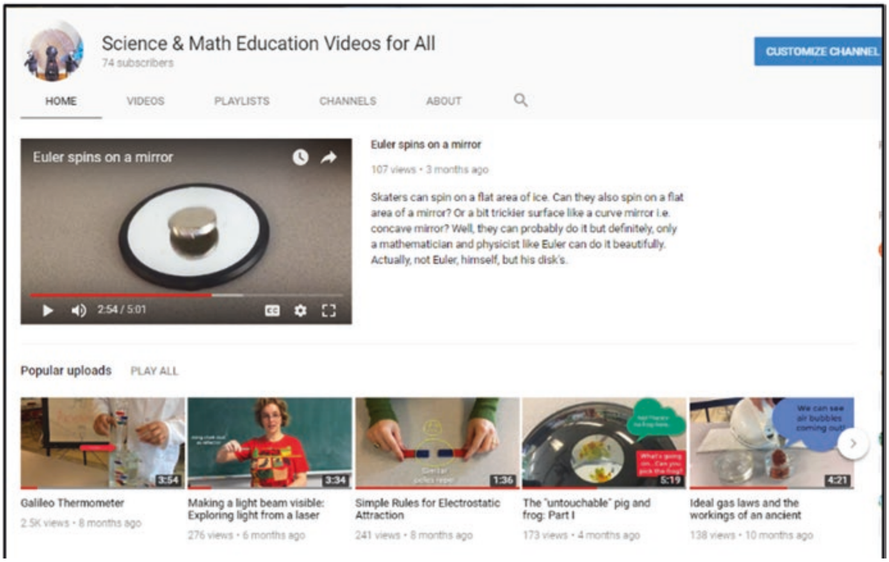
4.3 Collaborative Design of STEM Demonstration Videos

One of the prominent features of the new British Columbia STEM curriculum is its emphasis on the processes of science and science communication (British Columbia Ministry of Education, 2015). The same applies to other recent STEM curricular initiatives (DeCoito, 2016; The Royal Society Science Policy Centre, 2014). STEM teachers should be able to engage students in hands-on and inquiry-based learning while helping them appreciate mathematics and science as a way of knowing. In addition, the students ought to acquire communication skills and be able to relate STEM to their everyday lives. This means that STEM TCs should acquire these skills themselves before helping their own students. Unfortunately, due to time constrains, communication is rarely emphasized in undergraduate STEM curriculum and many TCs dread communicating about STEM outside of the classroom. To support TCs in developing these skills as well as the relevant pedagogies, in 2010 the author and her colleagues initiated the Family Mathematics and Science Day event at the Faculty of Education (Milner-Bolotin & Milner, 2017). This is a public STEM outreach event facilitated by TCs, staff, and faculty members. The event is aimed at families and the general public. During the day, TCs facilitate hands-on stations with activities and experiments engaging guests of different ages and backgrounds. While the event had grown enormously in the last 7 years (from 100 to more than 400 guests), it became apparent that TCs needed much more support in preparing for it. Moreover, the preparation for the event can include the design of educational resources that can be shared with other TCs and educators outside of the program. Thus, TCs become not only the consumers of the resources designed by others, but also the contributors to the STEM education community.

At the same time, as a growing number of schools in Canada are adopting a flipped classroom approach (Tucker, 2012), designing educational videos is becoming a valuable skill for STEM teachers. This inspired the introduction of an assignment in which TCs are asked to design a 5-min long educational video of STEM experiment or activity that they are going to conduct during the Family Mathematics and Science Day. TCs can choose any science concept that they would like to share with the guests. TCs could choose to do this assignment alone or collaborate with their peers (Milner-Bolotin, 2018c). During the preparation process they receive ample feedback from peers, the instructor, and educational technology expert who supported the video design. In addition, TCs were able to improve their video as a result of their experience with facilitating the activity to the real audience during the outreach event. At the end of the course, most of the videos (a few TCs asked not to share them) have been uploaded on the course YouTube channel (see Fig. 4), thus contributing to the STEM education community and creating a database of education resources.

5 Big Ideas for Technology Use in STEM Teacher Education

The three examples of technology-enhanced learning environments in STEM methods courses show that TCs should have an opportunity to experience these learning environments as students, then to reflect on them as future teachers and only then to consider how to implement them during their school practicum or in their teaching practice. STEM methods courses are perfect places for TCs to gain these experiences. Moreover, when TCs appreciate how their own knowledge of content and pedagogy has grown as a result of technology-supported collaboration, they are more likely to create similar experiences for their future students.



Skaters can spin on a flat area of ice. Can they also spin on a flat area of a mirror? Or a bit trickier surface like a curve mirror i.e. concave mirror? Well, they can probably do it but definitely, only a mathematician and physicist like Euler can do it beautifully. Actually, not Euler, himself, but his disk's.

Fig. 4 A screen shot of *Science & Math Education Videos for All* YouTube channel (Milner-Bolotin, 2018c)

During their school practicum, all of the TCs have used the materials they have created during their methods course collaboration and some TCs even created similar learning environments for their students. There are three big ideas that should drive the use of technology in STEM education as well as in STEM teacher education: learning goals are first, they are followed by the pedagogical consideration, and finally, technology that can enable these preferred pedagogies is considered. The DPTwT framework emphasizes it, as its stresses the teacher as the driver of technology and not the technology as a pedagogical driver. This makes teacher's role even more important, as the teacher orchestrates how and why different technologies are used and how these technologies can support student learning. This is a difficult task, so teacher collaboration and mutual support are important for accomplishing it. Thus, the growth of teacher knowledge comes as a result of collaboration with peers and experimentation with novel pedagogical approaches and analyzing their impact on students. This brings us back to the beginning of the paper, where the implications of modern technological developments were considered. In this chapter, we argue that new educational technologies will not replace teachers, but they will reshape teachers' roles. One might argue that teachers' work becomes even harder now as they have to learn to think critically about the pedagogical implications of using different technologies in their teaching. Here the educational research comes in. While teachers are not educational researchers, one might argue that they have to become "intelligent partners" with educational researchers (Martinovic, 2016), the same way students should become intelligent partners with technology (Martinovic, 2015; Martinovic & Manizade, 2014). Teachers in the twenty-first century have to be proactive in using educational research to inform their practice.

6 Summary

This paper outlines a novel – Deliberate Pedagogical Thinking with Technology (DPTwT) framework that can be especially valuable for guiding the design of learning environments in STEM methods courses that aim at inspiring and supporting the growth of TCs' knowledge for teaching. The DPTwT framework emphasizes the growth of teacher knowledge through collaboration with peers, often but not exclusively, facilitated by technology. Unlike other theoretical frameworks that examine teacher knowledge, DPTwT deliberately places technology in service of educational goals. It challenges educators first to articulate their pedagogical goals and only then to consider the technology that can help them achieve them. The technology is always secondary in this process (unless the goal is to learn how a specific technology works), while the well-articulated pedagogical goals and the results of educational research on student learning are always primary.

The *deliberate* in the DPTwT is the cornerstone of this framework as it emphasizes that teachers should be guided by the big educational goals and by the results of the context-specific educational research on how students learn STEM, and not by the allure of novel educational gadgets. This was emphasised in the three examples shown earlier. The ubiquitous use of technology without having a specific pedagogical justification for why this technology is being used has been one of the biggest educational shortcomings of the recent decades (Cuban et al., 2001). Too often educational technological innovations are driven by the people who do not have a strong pedagogical background or whose goals are not congruent with student learning. The confusing between the learning and entertainment is another problem (Postman, 1985). A SMART board failure is another example, where "the technological tail was unsuccessfully trying to wag the pedagogical dog" (Manny-Ikan & Dagan, 2011). The problem with these failures is not that they are costly, but that few school districts and educational administrators have learned from them. On the other hand, the design of PhET computer simulations is an opposite example, where educational research informs the technological innovations (Wieman et al., 2010). The PhET team uses education research as the driving force behind their simulation, in addition, the research is being done on how the simulations are being used and on their pedagogical effectiveness (Finkelstein et al., 2005).

This paper demonstrates how the DPTwT theoretical framework can be used to guide the design and implementation of different technology-rich assignments in the STEM methods courses. While these technology-enhanced pedagogies can also be used in other subject areas, they are especially valuable in STEM subjects, where the focus is on conceptual understanding and on the applications of key principles to a wide range of phenomena. For example, the use of Peer Instruction and

PeerWise is especially fitting for STEM subjects. Each one of these examples used technology that TCs can later implement in their own courses. The DPTwT framework can also provide a theoretical lens that guided the evaluation of the pedagogical effectiveness of these learning environments (Milner-Bolotin et al., 2016). In addition, the DPTwT framework supports the researchers in studying teacher knowledge from the perspective of growth through peer collaboration, mutual support, and the use of collaborative technologies. Three different but complementary pedagogical approaches discussed in the paper utilize PeerWise, CLAS, and video sharing and editing tools in STEM methods courses. The paper challenges teacher educators to consider how the modeling of technology-enhanced and research-based pedagogies in teacher education courses can help bridge educational research with educational practice.

References

Bates, S. P., Galloway, R. K., Riise, J., & Homer, D. (2014). Assessing the quality of a student-generated question repository. *Physical Review Special Topics - Physics Education Research, 10*, 020105.

British Columbia Ministry of Education. (2015). *Building students success: BC's new curriculum*. Author. https://curriculum.gov.bc.ca/. 2018.

Carl Wieman Science Education Initiative at the University of British Columbia. (2012). CWSEI – UBC. http://www.cwsei.ubc.ca/. 2015.

Chachashvili-Bolotin, S., Milner-Bolotin, M., & Lissitsa, S. (2016). Examination of factors predicting secondary students' interest in tertiary STEM education. *International Journal of Science Education, 38*, 366–390. https://doi.org/10.1080/09500693.2016.1143137

Chien, Y.-T., Chang, Y.-H., & Chang, C.-Y. (2015). Do we click in the right way? A meta-analytic review of clicker-integrated instruction. *Educational Research Review, 17*, 1–18. https://doi.org/10.1016/j.edurev.2015.10.003

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing and mathematics. In L. B. Resnick (Ed.), *Knowing learning and instruction* (Vol. 1, pp. 453–494). Hillsdale, NJ: Lawrence Erlbaum Associates.

Cuban, L. (2001). *Oversold and underused: Computers in the classroom*. Cambridge, MA: Harvard University Press.

Cuban, L., Kirkpatrick, H., & Peck, C. (2001). High access and low use of technologies in high school classrooms: Explaining an apparent paradox. *American Educational Research Journal, 38*, 813–834.

Dang, T. (2018). *Collaborative Learning Annotation System*. Vancouver, BC: UBC ETS.

DeCoito, I. (2016). STEM education in Canada: A knowledge synthesis. *Canadian Journal of Science, Mathematics and Technology Education, 16*, 114–128.

Denny, P. (2010). Motivating online collaborative learning. *ITiCSE, 37*, 300.

Denny, P. (2018). *PeerWise*. Auckland, NZ: The University of Auckland. http://peerwise.cs.auckland.ac.nz/. Accessed 22 Apr 2016.

Deslauriers, L., Schelew, E., & Wieman, C. E. (2011). Improved learning in a large-enrollment physics class. *Science, 332*, 862–864.

Dweck, C. S. (2016). *Mindset: The new psychology of success*. New York, NY: Penguin Random House.

Etkina, E. (2010). Pedagogical content knowledge and preparation of high school physics teachers. *Physical Review Special Topics, 6*, 020110.

Fagen, A. P., Crouch, C. H., & Mazur, E. (2002). Peer Instruction: Results from a range of classrooms. *The Physics Teacher, 40*, 206–209.

Finkelstein, N. D., Adams, W. K., Keller, C. J., Kohl, P. B., Perkins, K. K., Podolefsky, N. S., … LeMaster, R. (2005). When learning about the real world is better done virtually: A study of substituting computer simulations for laboratory equipment. *Physical Review Special Topics - Physics Education Research, 1*, 010103.

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics, 66*, 64–74.

Hardy, J., Bates, S. P., Casey, M. M., Galloway, K. W., Galloway, R. K., Kay, A. E., … McQueen, H. A. (2014). Student-generated content: Enhancing learning through sharing multiple-choice questions. *International Journal of Science Education, 36*, 2180–2194. https://doi.org/10.1080/09500693.2014.916831

Harris, J., Mishra, P., & Koehler, M. (2009). Teachers' Technological Pedagogical Content Knowledge and learning activity types: Curriculum-based technology integration reframed. *Journal of Research on Technology in Education, 41*, 393–416.

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. *The Physics Teacher, 30*, 141–157.

Jonassen, D., & Land, S. (2012). *Theoretical foundations of learning environments* (2nd ed.). New York, NY: Routledge.

Jones, M. G., & Leagon, M. (2014). Science teacher attitudes and beliefs: Reforming practice. In N. G. Lederman & S. K. Abel (Eds.), *Handbook of research on science education* (Vol. 2, pp. 830–847). New York, NY: Routledge.

Kalman, C. S., Milner-Bolotin, M., & Antimirova, T. (2010). Comparison of the effectiveness of collaborative groups and Peer Instruction in a large introductory physics course for science majors. *Canadian Journal of Physics, 88*, 325–332.

Khan, S. (2013). Khan Academy. http://khanacademy.org/. 2013.

Koehler, M. J., & Mishra, P. (2015). Technological pedagogical content knowledge. In M. J. Spector (Ed.), *The SAGE encyclopedia of educational technology* (Vol. 2, pp. 782–785). Los Angeles, CA: SAGE.

Kolikant, Y. B.-D. (2010). "Clickers" as catalysts for transformation of teachers. *College Teaching, 58*, 127–135. https://doi.org/10.1080/87567551003774894

Lasry, N. (2008). Clickers or flashcards: Is there really a difference? *The Physics Teacher, 46*, 242–244.

Lasry, N., Mazur, E., & Watkins, J. (2008). Peer Instruction: From Harvard to the two-year college. *American Journal of Physics, 76*, 1066–1069.

Lave, J. (1990). The culture of acquisition and the practice of understanding. In D. Kirschner & J. A. Whitson (Eds.), *Situated cognition: Social, semiotic and psychological perspectives* (Vol. 1, pp. 17–35). London, UK: Lawrence Erlbaum Associates.

Let's Talk Science. (2013). *Spotlight on science learning: The high cost of dropping science and math*. Toronto, ON: Author.

Let's Talk Science. (2016). *PISA 2015 gives cause for celebration but not complacency*. Toronto, ON: Author.

Levin, I., & Tsybulsky, D. (2017). *Digital tools and solutions for inquiry-based STEM learning*. Hershey, PA: IGI Global. https://doi.org/10.4018/978-1-5225-2525-7

Maciel, T. (2015). Smartphones in the classroom help students see inside the black box. *APS News, 24*, 5–6.

Manny-Ikan, E., Berger Tikochinski, T., & Bashan, Z. (Eds.). (2013). *Does the use of ICT-based teaching encourage innovative pedagogical interaction in the classroom? A presentation of CLI-O: Class learning interactions – Observation tool*. Jerusalem, Israel: Henrietta Szold Institute.

Manny-Ikan, E., & Dagan, O. (2011). Using the interactive white board in teaching and learning – An evaluation of the SMART CLASSROOM Pilot Project. *Interdisciplinary Journal of E-Learning and Learning Objects, 7*, 249–273.

Martinovic, D. (2015). Computer-supported Mathematics learning: Technology as a partner in learning Mathematics. In L. A. H. Rebollar, J. Antonio, J. López, & J. S. Ignjatov (Eds.), *Tendencias en la educación matemática basada en la investigación* [Trends in research-based mathematics education] (Vol. 1, pp. 53–66). Mexico, Mexico: Benemérita Universidad Autónoma de Puebla.

Martinovic, D. (2016). Educators as researchers: Connecting educational research and practice within a Teacher Education Program. In J. C. McDermott & A. Kožuh (Eds.), *Theoretical framework of education* (pp. 7–20). Los Angeles, CA: Antioch University.

Martinovic, D., & Manizade, A. G. (2014). Technology as a partner in geometry classrooms. *The Electronic Journal of Mathematics and Technology, 8*, 69–87.

Martinovic, D., Muller, E., & Buteau, C. (2013). Intelligent partnership with technology: Moving from a mathematics school curriculum to an undergraduate program. *Computers in the Schools, 30*, 76–101.

Martinovic, D., & Zhang, Z. (2012). Situating ICT in the Teacher Education Program: Overcoming challenges, fulfilling expectations. *Teachers and Teacher Education, 28*, 461–469.

Massachusetts Institute of Technology. (2018). *MIT open courseware*. Author. https://ocw.mit.edu/index.htm. Accessed 6 May 2018.

Mazur, E. (1997a). Peer Instruction: Getting students to think in class. In E. F. Redish & J. S. Rigden (Eds.), *Changing role of physics departments in modern universities: Proceedings of ICUPE, The University of Maryland* (p. 8). College Park, MD: American Institute of Physics.

Mazur, E. (1997b). *Peer Instruction: User's manual. Prentice Hall series in educational innovation*. Upper Saddle River, NJ: Prentice Hall.

Mazur, E. (2009). Farewell, lecture? *Science, 323*, 50–51.

McQueen, H. A., Shields, C., Finnegan, D. J., Higham, J., & Simmen, M. W. (2014). PeerWise provides significant academic benefits to biological science students across diverse learning tasks, but with minimal instructor intervention. *Biochemistry and Molecular Biology Education, 42*, 371–381. https://doi.org/10.1002/bmb.20806

Milner-Bolotin, M. (2012). Increasing interactivity and authenticity of chemistry instruction through data acquisition systems and other technologies. *Journal of Chemical Education, 89*, 477–481.

Milner-Bolotin, M. (2014). Using PeerWise to promote student collaboration on design of conceptual multiple-choice questions. *Physics in Canada, 70*, 149–150.

Milner-Bolotin, M. (2016a). Promoting deliberate pedagogical thinking with technology in physics teacher education: A teacher-educator's journey. In T. G. Ryan & K. A. McLeod (Eds.), *The physics educator: Tacit praxes and untold stories* (pp. 112–141). Champaign, IL: Common Ground and The Learner.

Milner-Bolotin, M. (2016b). Rethinking technology-enhanced physics teacher education: From theory to practice. *Canadian Journal of Science, Mathematics and Technology Education, 16*, 284–295. https://doi.org/10.1080/14926156.2015.1119334

Milner-Bolotin, M. (2017). Technology-supported inquiry in STEM teacher education: Collaboration, challenges and possibilities. In I. Levin & D. Tsybulsky (Eds.), *Digital tools and solutions for inquiry-based STEM learning* (Advances in educational technologies and instructional design (AETID) book series) (Vol. 1, pp. 252–281). Hershey, PA: IGI Global.

Milner-Bolotin, M. (2018a). Nurturing creativity in future mathematics teachers through embracing technology and failure. In V. Freiman, J. Tassell, & D. Martinovic (Eds.), *Creativity and technology in math education* (Mathematics education in the digital era) (p. 22). Cham, Switzerland: Springer.

Milner-Bolotin, M. (2018b). Promoting reflective physics teaching through the use of Collaborative Learning Annotation System. *The Physics Teacher, 56*, 313–316.

Milner-Bolotin, M. (2018c). *Science & math education videos for all*. UBC. https://www.youtube.com/channel/UCHKp2Hd2k_dLjODXydn2-OA. Accessed 20 Mar 2018.

Milner-Bolotin, M., Egersdorfer, D., & Vinayagam, M. (2016). Investigating the effect of question-driven pedagogy on the development of physics teacher-candidates' Pedagogical Content Knowledge. *Physics Review Special Topics - Physics Education Research, 12*, 1–16.

Milner-Bolotin, M., Fisher, H., & MacDonald, A. (2013). Modeling active engagement pedagogy through classroom response systems in a physics teacher education course. *LUMAT: International Journal on Math, Science and Technology Education, 1*, 523–542.

Milner-Bolotin, M., Kotlicki, A., & Rieger, G. (2007). Can students learn from lecture demonstrations: The role and place of interactive lecture experiments in large introductory science courses. *Journal of College Science Teaching, 36*, 45–49.

Milner-Bolotin, M., & Milner, V. (2017). Family Mathematics and Science Day at UBC Faculty of Education. *Physics in Canada, 73*, 130–132.

Muller, D. (2018a). *This will revolutionize education*. YouTube. https://www.youtube.com/watch?v=GEmuEWjHr5c. 2018.

Muller, D. (2018b). *Veritasium*. https://youtube.com/veritasium. Accessed 5 May 2018

NRC. (2013). *Next generation science standards: For states, by states*. Washington, DC: The National Academies Press, USA National Research Council.

OECD. (2016a). *PISA 2015 results in focus*. Paris, France: Author.

OECD. (2016b). *PISA 2015 results: Excellence and equity in education vol I*. Paris, France: Author.

OECD. (2016c). *PISA 2015 results: Policies and practices for successful schools vol II*. Paris, France: Author.

Postman, N. (1985). *Amusing ourselves to death: Public discourse in the age of show business*. New York, NY: Penguin Books.

Prensky, M. (2001a). Digital natives, digital immigrants Part I: A new way to look at ourselves and our kids. *On the Horizons, 9*, 1–6.

Prensky, M. (2001b). Digital natives, digital immigrants Part II: Do they really think differently? *On the Horizons, 9*, 1–9.

Quinn, H. (2011). A framework for K-12 science education. *American Physical Society News, 20*, 1–3. https://www.aps.org/publications/apsnews/201111/backpage.cfm?renderfo

Schmid, R. F., Bernard, R. M., Borokhovski, E., Tamim, R. M., Abrami, P. C., Surkes, M. A., … Woods, J. (2014). The effects of technology use in postsecondary education: A meta-analysis of classroom applications. *Computers & Education, 72*, 271–291.

Schmidt, D., Baran, E., Thompson, A., Koehler, M. J., Shin, T., & Mishra, P. (2009, April). Technological Pedagogical Content Knowledge (TPACK): The development and validation of an assessment instrument for preservice teachers. Paper presented at the 2009 Annual Meeting of the American Educational Research Association, April 13–17, San Diego, California.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*, 4–14.

Smith, M. K., Wood, W. B., Krauter, K., & Knight, J. K. (2011). Combining peer discussion with instructor explanation increases student learning from in-class concept questions. *CBE Life Sciences Education, 10*, 55–63. https://doi.org/10.1187/cbe.10-08-0101

The Royal Society Science Policy Centre. (2014). *Vision for science and mathematics education report*. Author. http://www.interacademies.net/File.aspx?id=25298. Accessed 18 Apr 2017

Tucker, B. (2012). The flipped classroom. *Education Next, 12*, 82–83.

Vygotsky, L. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Wenger, E. (1998). Communities of practice: Learning, meaning, and identity. In *Learning in dong: Social, cognitive, and computational perspectives*. Cambridge, UK: Cambridge University Press.

Wieman, C. E., Adams, W. K., Loeblein, P., & Perkins, K. K. (2010). Teaching physics using PhET simulations. *The Physics Teacher, 48*, 225–227.

Wieman, C. E., Rieger, G., & Heiner, C. (2014). Physics exams that promote collaborative learning. *The Physics Teacher, 52*, 51–53.

Marina Milner-Bolotin is an Associate Professor in science education in the Faculty of Education at the University of British Columbia, Vancouver, Canada. She holds a M.Sc. in theoretical physics from the Kharkov National University in Ukraine. She also holds M.A. and Ph.D. degrees in mathematics and science education from the University of Texas at Austin in 2001. At UT Austin, she investigated how project based instruction in physics courses for future elementary teachers affected their interest in science and their ability to do and teach science. She specializes in science and mathematics education and science outreach. She studies how technology can be used in teacher education to prepare mathematics and science teachers who will be able to engage twenty-first century students in meaningful learning. Her work has appeared in international peer-reviewed research journals, scientific books, conference proceedings, seminars, and workshops. Since 1993, she has been teaching science and mathematics in Israel, USA, China, and Canada to elementary students to university undergraduates in science programs, and to pre-service and in-service teachers. She has led many professional development activities for science in-service and pre-service teachers and university faculty. She is an author of an introductory physics textbook used by thousands of students. Before joining UBC, she was faculty member at Ryerson University in Toronto, Ontario. She has received numerous research and teaching awards and served on the Executive Board of Canadian and International science education associations. To learn more about her research and publications, visit her web site at: http://blogs.ubc.ca/mmilner/.

Teaching Mathematics in the Digital Era: Standards and Beyond

Michal Tabach and Jana Trgalová

1 Introduction

In all technologically advanced societies today, the question of whether information and communication technology (ICT) should be used in education, and especially in mathematics education, is no longer an issue. Nevertheless, the question of how to use technology effectively to improve mathematics learning and/or teaching remains pertinent. In a literature review on the "barriers to the uptake of ICT by teachers," Jones (2004) points out that "effective training is crucial if teachers are to implement ICT effectively in their teaching" (p. 8). This clearly raises the issue of (pre-service) teacher education (TE) and (in-service) teacher professional development (TPD) regarding the use of digital technology.

We began researching the issue of mathematics TE/TPD with respect to technology use in 2016 by surveying research on the uses of technology in upper secondary level mathematics education (Hegedus et al., 2017). Our review of a number of TE/TPD initiatives in the literature revealed that most cases report disappointment with the outcomes of these initiatives. One of the main explanations for this disappointment is the discrepancy between teachers' needs and TE/TPD contents (Emprin, 2010). While teacher educators often showcase successful examples of ICT use that they themselves designed and implemented, they rarely address the ways in which teachers can implement these activities. Likewise, Lagrange and Dedeoglu (2009) point to a disparity between teachers' expectations in terms of ICT use and the ICT potentialities revealed by research and presented by teacher educators. These findings

---

M. Tabach (✉)
Tel-Aviv University, Tel-Aviv, Israel
e-mail: tabachm@post.tau.ac.il

J. Trgalová
University of Lyon, Lyon, France
e-mail: jana.trgalova@univ-lyon1.fr

Y. Ben-David Kolikant et al. (eds.), *STEM Teachers and Teaching in the Digital Era*, https://doi.org/10.1007/978-3-030-29396-3_12

point to the need for ICT competency standards to delineate the specific knowledge and skills (mathematics) teachers need to integrate ICT effectively in the classroom.

We therefore searched for existing documents governing teachers' knowledge about teaching mathematics with technology (Tabach & Trgalová, 2017; Trgalová & Tabach, 2018). In analysing these documents, we referred to the *TPACK model* (Mishra & Koehler, 2006). This model, which is widely used in research about teachers' professional knowledge related to ICT, depicts how teachers' technological knowledge interacts with their pedagogical and content knowledge in successfully integrating ICT into teaching. We articulated the TPACK model with the theoretical construct of *double instrumental genesis* (Haspekian, 2011) outlined below (Sect. 2). Our preliminary findings, which were based on our analysis of international ICT frameworks for teachers (e.g., ISTE, 2008; UNESCO, 2011) as well as of several national standards (e.g., USA, Australia, Israel or France), show that only a few such standards exist at either the national or the international level for mathematics teachers, or even for teachers in general. Moreover, most of the existing standards are not specific either to subject matter or to school level. The theoretical lens of the TPACK combined with the double instrumental genesis concept reveal that some standards overemphasize technological knowledge (TK) while others are not sufficiently precise to inform teacher education programs despite taking all categories of TPACK knowledge into consideration. On the other hand, some standards emphasize the need to develop teachers' awareness of the added value of technology in terms of its impact on students' understanding of mathematics. Our theoretical frame overlooked this dimension.

The aim of our research reported in this chapter is twofold: (1) to pursue our investigation of existing ICT standards for (mathematics) teachers by expanding it to national policies and institutional frameworks in several OECD countries and Australia; and (2) to define a conceptual framework for capturing various dimensions of teachers' professional knowledge and skills oriented toward the use of digital technology.

The chapter is organized as follows. We begin by describing the theoretical framework (Sect. 2) we adopted in our research, followed by a description of the methodology we used for analysing existing ICT-related policies and frameworks (Sect. 3). In Sect. 4 we report the findings of our research and in Sect. 5 we further discuss the findings and propose a conceptual framework for defining teachers' ICT competencies.

2 Theoretical Framework

We sought to capture not only the cognitive dimension but also other dimensions, such as the affective dimension, which have been deemed important in relation to ICT integration. Hence, we chose to replace the TPACK model with the *pedagogical technology knowledge* (PTK) framework (Thomas & Hong, 2005; Thomas & Palmer, 2014). The PTK framework (Fig. 1) includes a number of teacher factors

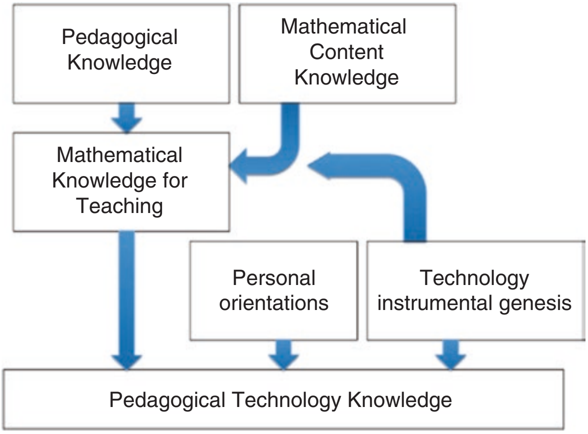


Fig. 1 Pedagogical technology knowledge framework (Thomas & Palmer, 2014)

intrinsic to the production of knowledge for teaching with technology, namely: teachers' instrumental genesis with respect to technology, mathematical knowledge for teaching (Ball, Thames, & Phelps, 2008), and teachers' personal orientations and goals (Schoenfeld, 2011), especially beliefs about the value of technology and the nature of learning mathematical knowledge as well as teachers' confidence in using technology.

We consider PTK to be an appropriate framework for examining mathematics teachers' technology-related knowledge for several reasons. First, it was developed within mathematics education specifically with mathematics teachers in mind, as indicated in reference to MKT (Ball et al., 2008), which is specific to mathematics education. Moreover, it further specifies important components of teachers' knowledge, such as knowledge of curriculum or students. Second, it includes an affective component by referring explicitly to teachers' orientation, which we consider to be an important dimension of teachers' professional competence, as noted by scholars such as Lynch, Russell, Evans, and Sutterer (2009) and Blömeke and Delaney (2012). Finally, the PTK framework explicitly refers to the technology-related instrumental genesis (Artigue, 2002). In other words, it acknowledges the process of using technological tools to achieve a set of goals, thus creating instruments in an ongoing process.

Nevertheless, we suggest two modifications to the PTK framework. First, instead of "technology instrumental genesis" we introduce the *double instrumental genesis* approach (Haspekian, 2011). In accordance with Rabardel's instrumental approach (2002), a user develops an *instrument* from an *artefact* used to accomplish a given task by elaborating usage schemes. This process is called *instrumental genesis*. The concept of *double instrumental genesis* acknowledges that teachers must develop two instruments from a given ICT tool (artefact): a mathematical instrument in a *personal instrumental genesis* (i.e., understanding how the tool transforms mathematics, being able to solve mathematical tasks with the tool, and so on) and a didactic instrument in a *professional instrumental genesis* (i.e., ability to use the tool to teach mathematics).

Second, we adapt Ball et al.'s (2008) categories of "mathematics knowledge for teaching" (MKT) to technology. Out of six knowledge areas in the MKT model, we adapt the following four to technology:

- specialized content knowledge that, in a technological environment, presents specificities related to the mathematics embedded in technology and thus needs to be redefined as *specialized digital content knowledge* (SDCK);
- knowledge of content and students, which in a technological environment includes additional aspects that may be formulated as *knowledge of digital content and students* (KDCS);
- knowledge of content and teaching that in a technological environment may be referred to as *knowledge of digital content and teaching* (KDCT);
- knowledge of content and curriculum in a digital environment, e.g., knowledge of prescribed use of ICT that should be redefined as *knowledge of digital content and curriculum* (KDCC).

We refer to the resulting model as "mathematical digital knowledge for teaching" (MDKT – Fig. 2).

These two modifications of the PTK lead to what we refer to as the "mathematical knowledge for teaching with technology" (MKTT) framework (Fig. 3).

To summarize, our proposed theoretical model of mathematical knowledge for teaching with technology (Fig. 3) comprises three domains: teachers' orientations (affective domain), teachers' knowledge (cognitive domain) and teachers' double instrumental genesis related to technology.

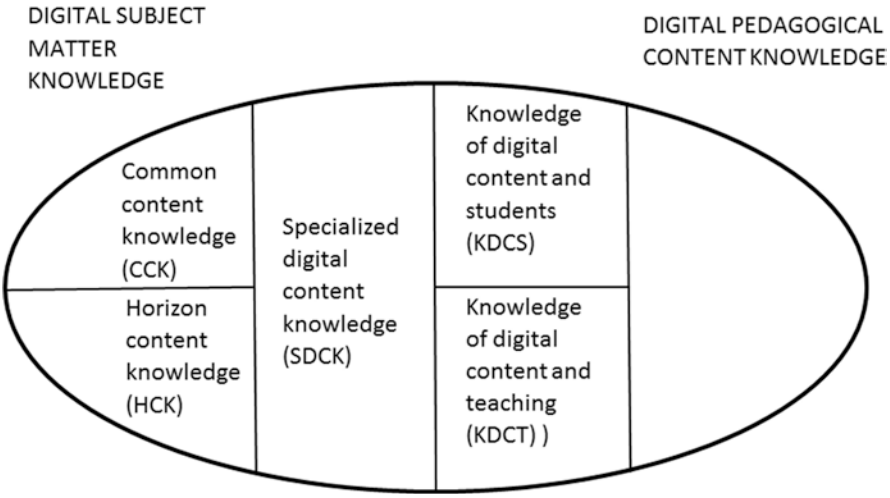


Fig. 2 Mathematical digital knowledge for teaching. (Adapted from Ball et al.'s mathematical knowledge for teaching to technological environment)

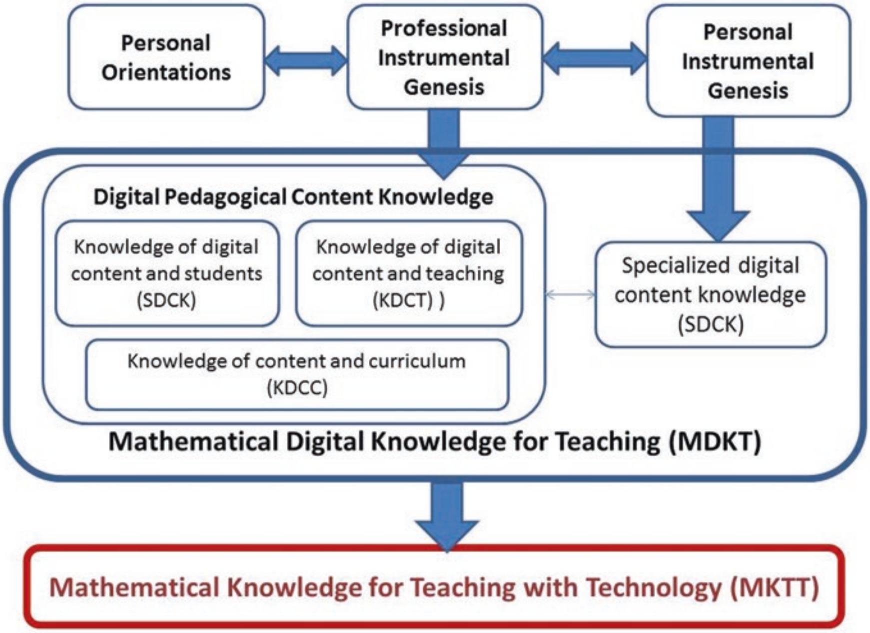


Fig. 3 Mathematical knowledge for teaching with technology framework

3 Methods

In this section, we describe the methodology we used to analyse several national and international policies. The analysis aims at highlighting specific ICT-related components made explicit in these policies that fall under the three main aspects outlined in our theoretical model (Fig. 3): cognitive domain, affective domain and double instrumental genesis perspective.

3.1 *Data Sources*

In pursuing our research aim, we looked for documentation written in English about standards or frameworks describing teachers' ICT-related knowledge, competencies and/or skills. We used the terms "knowledge," "skills," and "competencies," as these are the terms used by policymakers in official documents in various countries. We searched for current institutional documents, that is, documents at the national or international level that explicitly focus on teachers and teaching in digital environments. For example, in the US national documentation we found the *Standards for Preparing Teachers of Mathematics* (Association of Mathematics Teacher Educators, 2017), a comprehensive document aimed specifically at teachers specializing in mathematics and organized by grade levels and stages in the teachers' careers. However, the ICT component in this document was minor so we did not include it in our data set.

In the following sub-sections, we analyse two documents that describe frameworks for teaching with technology at the continental level: Europe (*European Framework for Digital Competence of Educators*) and Australia (*Australia National Framework for Professional Standards for Teaching*). We also analyse two national policies from two countries with a strong focus on ICT in education: Ireland (*Ireland Digital Strategy for Schools – Enhancing Teaching, Learning and Assessment*) and Norway (*Professional Digital Competence Framework for Teachers in Norway*).

3.2 Data Analysis

Although each document describes a web of connections between various elements, for the purpose of our analysis we attempted to separate these connections as follows. While reading the documents, we attempted to connect the statements made in each document to the components of our theoretical framework. Some statements referred to the *knowledge* base needed by teachers. This knowledge base might refer to mathematical knowledge, pedagogical knowledge or one of the six knowledge areas in the MDKT. Other statements focused on teachers' values, emotions or attitudes relevant to ICT integration. We grouped these under *personal orientations*. A third category in the documents referred to teachers' competencies—usually described as an ongoing process that refers to what teachers can do with technology for their own needs. We refer to this category as *personal instrumental genesis*. On the other hand, this category also noted that for their students to benefit from ICT as an integral part of their learning, teachers must search for digital resources, select the appropriate resources based on pedagogical and mathematical considerations, and create documents to be used by the students in class. We see this category as teachers' *professional instrumental genesis*.

4 Findings

4.1 European Framework for Digital Competence of Educators (DigCompEdu)

In 2017, the European Joint Research Centre[1] released a document introducing a framework for the digital competence of educators (Redecker, 2017). The framework was developed in response to

---

[1] The Joint Research Centre (JRC) is the European Commission's science and knowledge service. It aims to provide evidence-based scientific support to the European policymaking process.

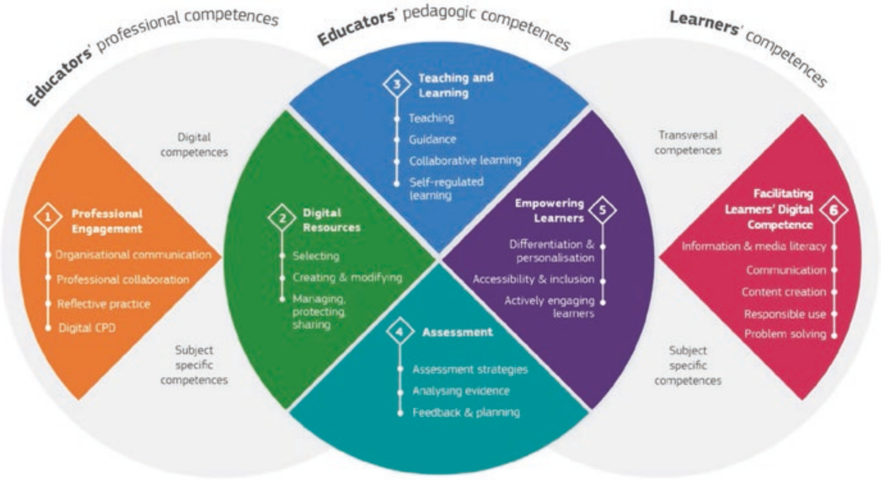


Fig. 4 DigCompEdu framework (Redecker, 2017, p. 19)

> the growing awareness among many European Member States that educators need a set of digital competences specific to their profession in order to be able to seize the potential of digital technologies for enhancing and innovating education (Redecker, 2017, p. 6).

The framework builds on analysis of existing national and international frameworks and self-assessment tools to obtain "educator-specific digital competences" (p. 9).

In this document, digital competence is defined as

> the confident, critical and creative use of ICT to achieve goals related to work, employability, learning, leisure, inclusion and/or participation in society (p. 90).

The framework identifies 22 elementary competencies organized into six areas that cover all facets of the education profession (Fig. 4). Area 1 concerns educators' use of digital technology in professional communication and collaboration with colleagues, learners, parents and other actors in education, as well as for their own individual development. Area 2 covers competencies needed for effective and responsible use, creation and sharing of digital resources. Area 3 focuses on the management and orchestration of digital technology in teaching and learning. Area 4 depicts competencies needed for using technology to enhance assessment. Area 5 details competencies needed for using learner-centred strategies with technologies. Finally, Area 6 focuses on the specific pedagogic competencies required to facilitate students' digital competence. According to the authors, Areas 2–5 constitute the core of the framework, which details

> educators' digital pedagogic competence, i.e. the digital competences educators need to foster efficient, inclusive and innovative teaching and learning strategies (p. 16).

We therefore focus on these areas, which we analyse through the lens of our theoretical framework.

Personal orientation. The DigCompEdu framework seems to overlook the need to foster the personal orientation dimension. In particular, it takes for granted that educators, even those who are newcomers and whose proficiency level[2] with technology is lowest, are aware of technology's potential for enhancing teaching and learning. Although confidence with technology use constitutes the very essence of the definition of digital competence, the framework does not consider this an issue and assumes that development of professional digital competence will result in increased confidence:

> The proficiency statements are designed to celebrate achievements and to encourage educators to develop their competences, by indicating small steps that will eventually, step by step, increase their confidence and competence (p. 28).

Personal instrumental genesis seems to be considered only in Area 1 in relation to technologies for communication and collaboration. Pedagogical digital competencies in Areas 2–5 appear to build on the educators' "existing digital competence" that they will apply "in the pedagogical realm" (p. 30).

The competencies described in Areas 3 and 4 are related to *professional instrumental genesis.* More specifically, competence 3.1, which is titled "teaching" and is deemed to be fundamental to the entire framework, can be considered to cover professional instrumental genesis of technology for teaching and learning. It covers competencies to be used in the following activities:

> To plan for and implement digital devices and resources in the teaching process, so as to enhance the effectiveness of teaching interventions. To appropriately manage and orchestrate digital teaching strategies. To experiment with and develop new formats and pedagogical methods for instruction (p. 21).

Similarly, competence 4.1 titled "assessment strategies" can be considered a professional genesis of technology for assessment purposes. It covers competencies to be mobilized in the following activities:

> To use digital technologies for formative and summative assessment. To enhance the diversity and suitability of assessment formats and approaches (p. 21).

(Mathematics) digital knowledge for teaching. Although the framework is not subject-matter-specific, Areas 3 and 4 refer to the content to be taught. Competencies that imply knowledge of content and teaching with technology (KDCT) can be seen in the following activities:

> To structure the lesson so that different (teacher-led and learner-led) digital activities jointly re-inforce the learning objective. To set up learning sessions, activities and interactions in a digital environment. To structure and manage content, collaboration and interaction in a digital environment. To consider how educator-led digital interventions—whether face-to-face or in a digital environment—can best support the learning objective. To reflect on the effectiveness and appropriateness of the digital pedagogical strategies chosen and flexibly adjust methods and strategies. (3.1 – Teaching, p. 52)

---

[2] The DigCompEdu framework considers six stages of digital competence development: newcomer (A1), explorer (A2), integrator (B1), expert (B2), leader (C1) and pioneer (C2). For more information, see Redecker (2017, pp. 28–29).

Competencies implying knowledge of digital content and students (KDCS) manifest themselves in the activities as follows:

> To set up learning activities in digital environments, having foreseen learners' needs for guidance and catering for them (3.2 – Guidance, p. 54),

or

> To assist learners in identifying areas for improvement and jointly develop learning plans to address these areas (4.3 – Feedback and planning, p. 66).

Finally, competencies implying pedagogical knowledge and technology are addressed in Area 3: "to use classroom technologies to support instruction, e.g. electronic whiteboards, mobile devices"; "to experiment with and develop new formats and pedagogical methods for instruction (e.g. flipped classroom)" (3.1 – Teaching, p. 52); "to experiment with and develop new forms and formats for offering guidance and support, using digital technologies" (3.2 – Guidance, p. 54).

4.2 Australia National Framework for Professional Standards for Teaching

In 2003, the Ministerial Council on Education, Employment, Training and Youth Affairs in Australia published a document defining the *National Framework for Professional Standards for Teaching* (MCEETYA, 2003). The aim of the framework was to provide

> an architecture within which generic, specialist and subject-area specific professional standards can be developed at National, and State and Territory levels (p. 2).

The framework seeks to define

> what constitutes quality teaching and facilitates the articulation of the knowledge, understandings, skills and values for effective teaching through development of standards at the local level (p. 5).

The framework is based on four professional elements—Professional Knowledge; Professional Practice; Professional Values; and Professional Relationships—and comprises four career dimensions: Graduation; Competence; Accomplishment; and Leadership, as illustrated in Fig. 5.

This framework, however, does not refer to digital context. Five years later, a *Joint Ministerial Statement on Information and Communications Technologies in Australian Education and Training: 2008–2011* was published. This short document[3] states that

> Australia will have technology enriched learning environments that enable students to achieve high quality learning outcomes and productively contribute to our society and economy.

---

[3] See https://files.eric.ed.gov/fulltext/ED534395.pdf

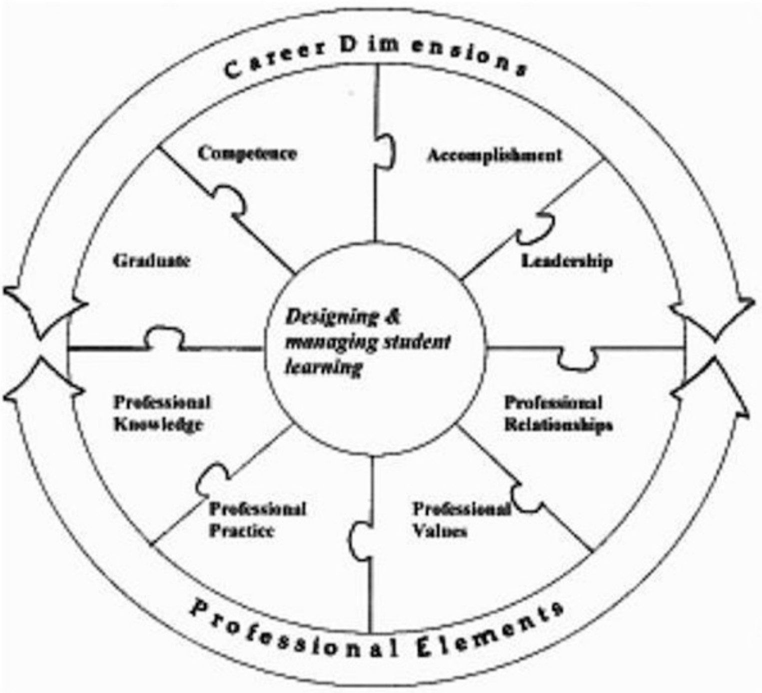


Fig. 5 Australia national framework for professional standards for teaching

This document also led to new teaching considerations. Education Services Australia (ESA) published *Pedagogies and Digital Content* (Baker, 2009), a document that includes a historical overview of Australian efforts to define criteria for teachers at the national level and at the local level of countries in which such development took place. This comprehensive overview is guided by six research questions, one of which is of interest for our study:

> What skills and capabilities will teachers need in order to access and use repositories of suitable, exciting, culturally appropriate, discoverable and affordable digital content? (p. 1).

The Australian strategic plan adopted the UNESCO ICT Competency Framework (2011), which it saw as a good basis upon which to build a more specific plan and as a basis for assessing progress. The strategic plan also used the UNESCO ICT Competency Framework as a text suggesting the next steps to be taken. The authors of the Australian strategic plan claim that the UNESCO's ICT Competency Standards for Teachers

> define the ICT-related skills required of teachers in primary and secondary schools. They take as their starting point the assumption that new technologies require new teacher roles, pedagogies, and approaches to teacher training (p. 26).

This interpretation has implications regarding the impact of ICT use on

> the skills required of teachers in managing classrooms in which such ICT-related interaction and collaboration are used for teaching and learning (p. 26).

Although the terms “skills” and “competencies” are central, they are not defined in the document.

The *National Framework for Professional Standards for Teaching* (MCEETYA, 2003) was developed to provide a

> basis for agreement on and consistency around what constitutes quality teaching and facilitates the articulation of the knowledge, understandings, skills and values for effective teaching through development of standards at the local level (p. 24).

We now analyse the document via our *Mathematical Knowledge for Teaching with Technology Framework* (Fig. 3).

Personal orientation. The term “values” appears in the declared aim. While this notion is not further developed, we believe it resonates with the teachers’ personal orientation towards technology integration.

We could not find any specific reference to *personal instrumental genesis* or to *professional instrumental genesis* in the document.

In terms of *subject-specific knowledge*, we did not find any explicit reference to specialized digital content knowledge (SDCK), yet we did find references to the other three types of knowledge.

Knowledge of content and students (KDCS). The plan states that teachers must be familiar with theories about students’ learning that take into account the use of ICT. Such familiarity will allow teachers to develop a detailed understanding of how young people learn, and in particular provide them with a clear understanding of the role of the teacher in leading this endeavour.

Knowledge of content and teaching (KDCT) and *knowledge of content and curriculum* (KDCC). The document relates to both of these knowledge areas, as it sees teachers as the designers of learning activities: “using a range of techniques, tools, practices and resources” (p. 25). To do so, teachers must be familiar with the curriculum in digital environments and at the same time must understand content and teaching in these environments. As noted by Baker (2009), however, the document does not anticipate that

> teachers might need to encourage cross-disciplinary thinking, social interaction and the use of digital media, or be able to provide students with state-of-the-art tools in technology-rich learning environments (p. 25).

4.3 Ireland Digital Strategy for Schools: Enhancing Teaching, Learning and Assessment

In 2015, the Department of Education and Skills in Ireland published a comprehensive strategic plan for ICT integration in K-12: *Digital Strategy for Schools: 2015–2020. Enhancing Teaching, Learning and Assessment* (Strategy Development Group, 2015). The plan includes four themes: Teaching, Learning and Assessment Using ICT; Teacher Professional Learning; Leadership, Research and Policy; and ICT Infrastructure. In other words, this strategic plan views teachers as central actors in the successful implementation of ICT in schools. The second theme is the focus of our interest in this chapter.

In line with Butler, Leahy, Shiel, and Cosgrove (2013), the strategic plan makes the following basic assumption:

> The concept of teaching and learning through the use of ICT is highly complex. The introduction of ICT into a learning environment does not in and of itself bring about change in pedagogical practice (p. 19).

Hence, a major effort is needed to provide teachers with various PD opportunities for professional development.

The Ireland Digital Strategic Plan adopted the UNESCO ICT Competency Framework (2011). On the one hand, this framework provides teachers, school principals and PD providers with a landscape for examining and evaluating the current situation and outlines future steps in various directions. On the other hand, the framework must be adapted to the Irish context.

The strategic plan uses the terms “practice,” “knowledge and skills” and “confidence” with respect to the need to support teachers’ PD. Yet only knowledge is made explicit to some extent. The meaning of teacher “practice,” “skills” and “confidence” is taken for granted and no definitions are provided for these terms. With respect to knowledge, the plan refers to the TPACK framework (Mishra & Koehler, 2006) as a means of approaching the knowledge teachers need. This is a rather naïve view of this framework. As noted by Voogt, Fisser, Pareja Roblin, Tondeur, and van Braak (2012), this framework has three different interpretations: T(PCK) as extended PCK; TPCK as a unique and distinct body of knowledge; and TP(A)CK as the interplay between three domains of knowledge and their intersections. From the way the strategic plan describes TPACK, it seems the authors implicitly adopt the last view, acknowledging that besides

> the three types of knowledge required by a teacher for effective pedagogical practice in a technology enhanced learning environment namely, technological knowledge, knowledge of curriculum content and pedagogical knowledge, [e]qually important to the model are the interactions between these bodies of knowledge. When teachers effectively integrate these areas of knowledge, they can embed ICT effectively into their practice (p. 29).

We now analyse the second theme in the strategic plan—teachers’ professional learning—via our *Mathematical Knowledge for Teaching with Technology Framework* (Fig. 3).

Personal orientation. The Ireland Digital Strategic Plan acknowledges that teachers need to develop “confidence to embed ICT more into their practice” (p. 31). Moreover, the plan states that supporting and building this confidence should be an ongoing activity in PD “throughout a teacher’s career” (p.32).

Personal instrumental genesis. Some reference to this issue is apparent in the following quote: “ALL teachers should have the requisite knowledge and skills to integrate ICT effectively into their practice” (p. 30). While this does not state directly that this knowledge refers to teachers’ ability to use ICT for their own needs, it is the closest thing to such a statement.

Professional instrumental genesis. The strategic plan acknowledges the fact that technology itself has developed and changed at a rapid pace. Hence, learning how to integrate ICT to promote students' learning as a single event is not sufficient. Rather, learning must continue throughout a teacher's professional lifetime. Moreover, the plan encourages PD developers to provide "teacher professional learning in a range of formats," emphasizing that "teacher professional learning needs to be rooted in classroom practice" (p. 31).

Pedagogical knowledge is referred to in this statement about ICT implementation:

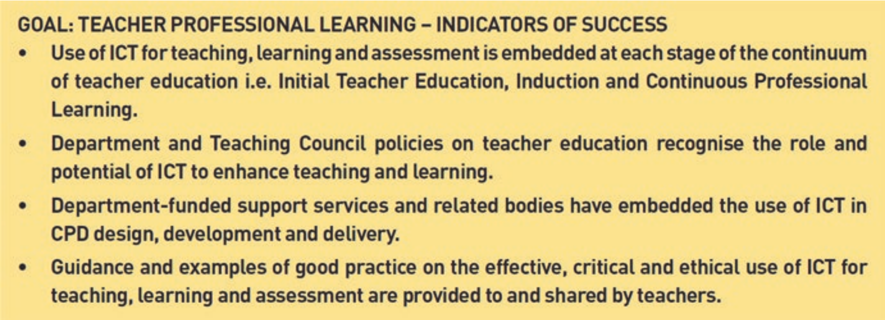
> all forms of teacher professional learning should highlight a range of pedagogical practices that support the active use of ICT by learners in a range of settings (p. 32).

In contrast, no references are made to mathematical knowledge or any other subject-matter knowledge. The strategic plan is general and addresses teachers of all school subjects. Nevertheless, the document does hint at the need to develop subject-matter knowledge by recommending the use of PD in "subject-department approaches" (p. 31). The strategic plan also lacks references to MKT or any other subject-specific knowledge: specialized digital content knowledge, knowledge of content and students, knowledge of content and teaching, and knowledge of content and curriculum.

Note that this strategic plan is aimed at the 5 years period from 2015 to 2020. The plan lacks any specificity in terms of grades or levels, yet it does define the following indicators for its success (Fig. 6).

4.4 Professional Digital Competence Framework for Teachers in Norway

The Norwegian Centre for ICT in Education was established in 2010 as an agency under the direct authority of the Norwegian Ministry of Education and Research. Its mission is "to help ensure that ICT is used to improve the quality of education,



GOAL: TEACHER PROFESSIONAL LEARNING – INDICATORS OF SUCCESS

- Use of ICT for teaching, learning and assessment is embedded at each stage of the continuum of teacher education i.e. Initial Teacher Education, Induction and Continuous Professional Learning.
- Department and Teaching Council policies on teacher education recognise the role and potential of ICT to enhance teaching and learning.
- Department-funded support services and related bodies have embedded the use of ICT in CPD design, development and delivery.
- Guidance and examples of good practice on the effective, critical and ethical use of ICT for teaching, learning and assessment are provided to and shared by teachers.

Fig. 6 Indicators for success (e-Digital Strategy Development Group, 2015, p. 30) learning outcomes and learning strategies for young children, pupils and students." In 2017, the Centre released a document outlining a framework for digital competence among teachers (Kelentrić, Helland, & Arstorp, 2017). According to the authors, the framework builds on competence areas of the teaching profession "viewed from a digital perspective" (p. 3). The framework comprises seven competence areas that contain descriptions of knowledge, skills and competence. We begin by examining the meaning the framework assigns to the terms "skills" and "competence" (note that the term "knowledge" is not defined in the document).

The glossary annexed to the document includes the following definition of competence:

> **Competence** means acquiring and using knowledge and skills to master challenges and solve tasks in familiar and unfamiliar contexts and situations. Competence entails understanding, and the capacity for reflection and critical thinking (p. 11).

Digital competence is further defined as

> the confident, critical, and creative use of ICT to achieve goals related to work, employability, learning, leisure, inclusion and/or participation in society. Digital competence is a transversal key competence which enables the acquisition of other key competencies. It is related to many of the so-called '21st Century skills', which should be acquired by all citizens, to ensure their active participation in society and the economy (p. 11).

This definition clearly draws on the definition provided by the EU in its DigComp framework. Finally, **digital skills**

> involve being able to use digital tools, media and resources efficiently and responsibly, to solve practical tasks, find and process information, design digital products and communicate content. Digital skills also include developing digital judgement by acquiring knowledge and good strategies for the use of the Internet (p. 14).

The Norwegian framework for the digital competence of teachers (Fig. 7) is organized into seven competence areas covering the various facets of the teaching profession. The authors indeed claim that:

> All of the areas of competence are equally important, but it is the sum of the competence areas that makes up a professional, digitally competent teacher (p. 14).

In the following sections we analyse the Norwegian framework through the lens of our theoretical framework.

Personal orientation. This dimension of teachers' competence is missing from the framework. The assumption may be that a positive attitude toward the use of technology in education appears to be self-evident and is not an issue.

Personal instrumental genesis. The framework acknowledges the need for teachers to develop their own digital skills, which they are expected to do during their primary and secondary education. Indeed, entering students in teacher education programs are expected to have already developed basic digital skills

> so they can search for and process information, produce and communicate online, as well as exercise digital judgement (p. 1).

Professional instrumental genesis is emphasized in the framework as a lifelong process that begins during the teachers' initial teacher education:

Fig. 7 Professional digital competence framework for teachers (Kelentrić et al., 2017, p. 3)

> In order to be capable of developing pupils' basic skills and specialised knowledge, teachers must develop their own professional digital competence during their initial teacher education, and later, through continuing professional education and development, during their teaching career (p. 1).

(Mathematics) digital knowledge for teaching (MDKT). Although the framework is not subject-matter specific, two competence areas explicitly mention the content to be taught: (a) subjects and basic skills and (b) pedagogy and subject didactics.

The subjects and basic skills area states that:

> A professional, digitally competent teacher understands how digital developments are changing and expanding the content of subjects. The teacher understands how the integration of digital resources into learning processes can help to achieve competence aims in a subject, and to address the five basic skills. […] At the same time, the teacher needs to understand what pupils' digital skills entail, and how they can be fostered in the subjects (p. 4).

Understanding "how digital developments are changing and expanding the content of subjects" requires specialized digital content knowledge (SDCK), while understanding "how the integration of digital resources into learning processes can help to achieve competence aims in a subject" implies knowledge of content and teaching with technology (KDCT). Moreover, understanding "what pupils' digital skills entail and how they can be fostered in the subjects" requires knowledge of digital content and students (KDCS).

According to the pedagogy and subject didactics area:

> A professional, digitally competent teacher possesses pedagogical knowledge, as well as knowledge of subject didactics relevant to the practice of their profession in a digital environment. Based on this, the teacher integrates digital resources into their planning, organisation, implementation and evaluation of the teaching in order to foster pupils' learning and development (p. 7).

This area thus addresses pedagogical as well as content knowledge in relation to digital technology (MDKT).

5 Discussion

We begin this section by discussing the meanings of the central terms—e.g., knowledge, skills, and competency—we found in each document. We follow this by suggesting refinements in our theoretical framework (Fig. 3) based on new findings reported in the previous section. Finally, we discuss further directions for study.

5.1 Central Terms

One notable observation stemming from our analysis is related to the inconsistencies in vocabulary across the four documents. Table 1 outlines the terms mentioned in the documents of the various institutions and clearly shows that each document uses its own terms. We were surprised to find that in some documents these terms are not defined at all (denoted by shaded cells in Table 1). In particular, the definition of "knowledge" in the Ireland document is indirect—the authors refer to the TPACK as a framework to define it. The term "competence" is also problematic. For example, the Norway framework is organized around seven competence areas, yet each of these competence areas is decomposed into three components: knowledge, skills and competence. This illogical and confusing definition of the term "competence" makes it difficult to grasp the meaning assigned to it.

The UNESCO framework defines competence as "the skills, knowledge and understanding needed to do something successfully" (UNESCO, 2011, p. 92). This same concept was also defined by the EU DigComp framework. Moreover, the Norwegian framework's definition draws on that of the EU in the following way:

> Competence means acquiring and using knowledge and skills to master challenges and solve tasks in familiar and unfamiliar contexts and situations. Competence entails understanding, and the capacity for reflection and critical thinking.

This definition broadens the one given by UNESCO.

Only the Norwegian framework defines digital skills as involving

Table 1 Various terms used in the documents to designate what teachers need in order to integrate ICT

	Australia	Ireland	Norway	EU	UNESCO
Knowledge	+	▨ +	+		
Understanding	+				
Skills	+	+	▨ +		
Competence/ competency			▨ +	▨ +	▨ +
Activity as an expression of a competence				+	
Capabilities	+				
Practice		+			
Confidence		+			
Values	+				

+ Means that the term appears in the document; shaded cell means that the term is not defined in the document; empty cell means that the term does not appear in the document

> being able to use digital tools, media and resources efficiently and responsibly, to solve practical tasks, find and process information, design digital products and communicate content. Digital skills also include developing digital judgement by acquiring knowledge and good strategies for the use of the Internet (p. 14).

We found a comparison between competency and skills in an OECD document:

> A competency is more than just knowledge or skills. It involves the ability to meet complex demands, by drawing on and mobilising psychosocial resources (including skills and attitudes) in a particular context. For example, the ability to communicate effectively is a competence that may draw on an individual's knowledge of language, practical IT skills and attitudes towards those with whom he or she is communicating (OECD, 2003, p. 4).

It seems that both skills and competency are related to taking action—in our case actions taken by the teacher in a technological environment. Yet skills seem to be "less" than competency. Knowledge is a basis for both skills and competency, but the connections between these concepts are not specified. Clearer definitions of the basic terms in each frame are necessary.

5.2 *Refining Our Framework*

In our model of teachers' professional knowledge and skills for teaching mathematics with technology, cognitive and affective domains as well as personal and professional instrumental genesis emerge as relevant in terms of capturing what teachers must develop to be able to use technology efficiently.

Nevertheless, we found that two of the documents we analysed—EU (Redecker, 2017) and Australia (Baker, 2009)—placed major emphasis on teachers' ability to search in digital repositories for suitable resources, to select those resources best suited to their students' needs, to create new digital resources themselves or with their team members, to share their resources with their peers, as well as to evaluate the resources' efficiency and appropriateness with respect to the learning objective. This is a rather new aspect not put forward in documents we studied previously. In the documentational approach to didactics (Gueudet & Trouche, 2009; Trouche, Gueudet, & Pepin, 2018) that draws on the instrumental approach, this facet of teachers' work with (digital) resources is called *documentation work*. We believe that this important part of teachers' professional work is captured by our framework in the professional instrumental genesis. Moreover, it is linked to teachers' knowledge both of content and of students, which in a technological environment includes additional aspects that may be formulated as knowledge of digital content and students (KDCS) and knowledge of content and curriculum in a digital environment (KDCC). With respect to our framework, we thus deem documentation work as a way to operationalize what we refer to as professional instrumental genesis.

In our framework, we contend that personal orientation impacts the way a teacher will use (or not use) digital technology. We assume that a positive opinion of the potential of technology for teaching and learning is a prerequisite (but of course not sufficient) for successful technology integration. The EU DigCompEdu framework seems to suggest that the development of digital competence will increase educators' confidence in using technology in teaching and learning. Moreover, the Ireland document considers confidence as something that needs to be nurtured throughout a teacher's professional lifetime.

People who enter the teaching profession today are considered to be digital natives (Prensky, 2001). Hence one might assume that those in this population have a positive attitude toward technology and a high level of personal digital mastery, so that personal orientation and personal instrumental genesis are self-evident. This seems to be the case in the Norwegian framework that expects student teachers to have acquired basic digital skills during their primary and secondary education. Yet from our experience with teacher educators, we know that personal instrumental genesis of mathematics-specific technology is far from self-evident among most young teachers. Consequently, in our view, it is an important component of teachers' ICT competence.

The findings reported in Sect. 4 have led us to refine our MKTT framework. We contend that the cognitive and affective dimensions along with the double instrumental genesis are important components of competent technology use for mathematics teachers. Moreover, consistent with the authors of the OECD (2003) document, we acknowledge that competence is more than merely knowledge and skills, as competence draws on knowledge, skills and attitudes. Therefore, although here we have chosen to refrain from entering the debate about the definition of competence, we believe that our model depicts what we propose calling *digital competencies for teaching mathematics with technology* (Fig. 8).

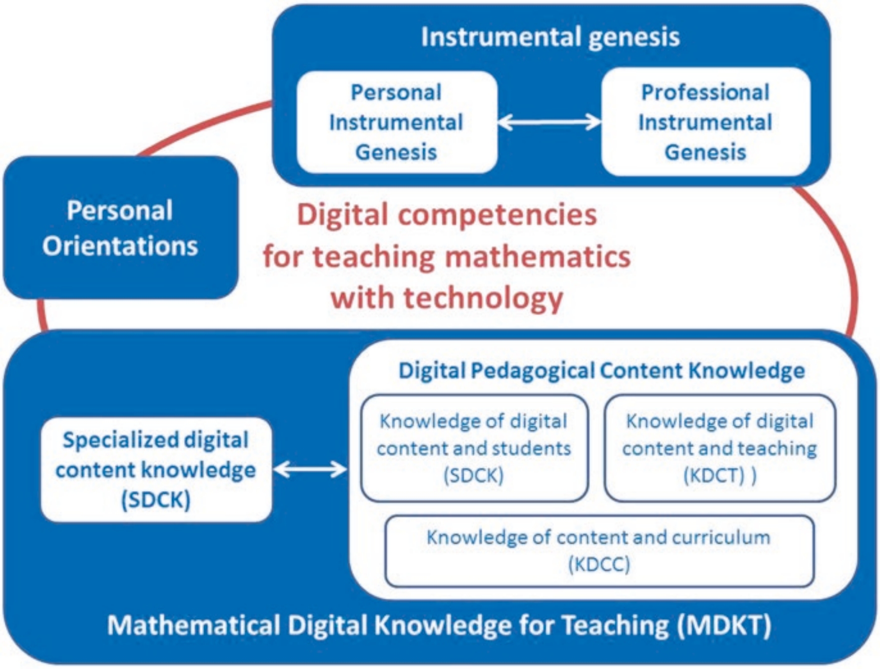


Fig. 8 Digital competencies for teaching mathematics with technology

5.3 Further Directions for Study

Our previous research has led us to appeal to the mathematics education community to advocate the issue of elaborating ICT standards for mathematics teachers:

> We call on the mathematics education research community to consider elaborating sets of standards for teaching with ICT for different age groups and school subjects so as to allow for the promotion of the professional level of instrumental genesis (Trgalová & Tabach, 2018, p. 351).

Our analysis of the documents in this chapter indicates that these issues are still under-developed. Standards for teacher competencies that are both subject-specific and age-specific are still missing. The P21[4] took a first step in this direction in that, together with the NCTM and MAA, it developed examples of student competencies to be achieved by the end of the 4th, 8th and 12th grades in mathematics. This approach needs to be expanded to define the work required of teachers to achieve these competencies. We believe that leaders of mathematics education in every country should undertake similar steps.

---

[4] P21 Partnership for 21st Century Learning, www.P21.org

Our proposed digital competencies for teaching mathematics with technology framework (Fig. 8) was developed and used in a dialectical process of implementation and refinement. Until now, however, the framework has only been implemented to study policy documents. As a next step in our research endeavour, we seek to implement the framework on data stemming from empirical studies involving the work of mathematics teachers both before and after teaching an ICT-based mathematics lesson in order to determine whether and to what extent the framework is suitable for evaluating teachers' ICT competencies.

References

Artigue, M. (2002). Learning mathematics in a CAS environment: The genesis of a reflection about instrumentation and the dialectics between technical and conceptual work. *International journal of computers for mathematical learning, 7,* 245–274.

Association of Mathematics Teacher Educators. (2017). *Standards for preparing teachers of mathematics*. Retrieved April 2018, from http://amte.net/standards

Baker, R. (2009). *Pedagogies and digital content in the Australian school sector*. Retrieved April 2018, from http://www.ndlrn.edu.au/verve/_resources/ESA_Pedagogies_and_Digital_Content_in_the_Australian_School_Sector.pdf

Ball, L. D., Thames, M. H., & Phelps, G. (2008). Content knowledge for teaching: What makes it special? *Journal of Teacher Education, 59*(5), 389–407.

Blömeke, S., & Delaney, S. (2012). Assessment of teacher knowledge across countries: A review of the state of research. *ZDM Mathematics Education, 44*, 223–247.

Butler, D., Leahy, M., Shiel, G., & Cosgrove, J. (2013). *A consultative paper – Building towards a learning society: A national digital strategy for schools*. Education Research Centre, St Patrick's College. Retrieved May 2018, from https://www.education.ie/en/Schools-Colleges/Information/Information-Communications-Technology-ICT-in-Schools/Digital-Strategy-for-Schools/Building-Towards-a-Learning-Society-A-National-Digital-Strategy-for-Schools-Consultative-Paper.pdf

Digital Strategy Development Group. (2015). *Digital strategy for schools 2015–2020. Enhancing teaching, learning and assessment*. Department of Education and Skills, Ireland. Retrieved May 2018, from https://www.education.ie/en/Publications/Policy-Reports/Digital-Strategy-for-Schools-2015-2020.pdf

Emprin, F. (2010). A didactic engineering for teachers education courses in mathematics using ICT. In V. Durand-Guerrier et al. (Eds.), *Proceedings of the sixth congress of the European Society for Research in Mathematics Education (CERME6)* (pp. 1290–1299). Lyon, France: INRP.

Gueudet, G., & Trouche, L. (2009). Towards new documentation systems for mathematics teachers? *Educational Studies in Mathematics, 71*(3), 199–218.

Haspekian, M. (2011). The co-construction of a mathematical and a didactical instrument. In M. Pytlak, T. Rowland, & E. Swoboda (Eds.), *Proceedings of the 7th congress of the European Society for Research in Mathematics Education (CERME7)* (pp. 2298–2307). Rzeszów, Poland: University of Rzeszów.

Hegedus, S., Laborde, C., Brady, C., Dalton, S., Siller, H.-S., Tabach, M., …, Moreno-Armella, L. (2017). *Uses of technology in upper secondary mathematics education*. ICME13 Topical Surveys. Springer. Retrieved May 2018, from https://link.springer.com/content/pdf/10.1007%2F978-3-319-42611-2.pdf

ISTE. (2008). *ISTE standards for teachers*. Retrieved July 2018, from http://www.iste.org/standards/standards/standards-for-teachers

Jones. (2004). *A review of the research literature on barriers to the uptake of ICT by teachers*. British Educational Communications and Technology Agency (BECTA). Retrieved May 2018, from http://dera.ioe.ac.uk/1603/1/becta_2004_barrierstouptake_litrev.pdf

Kelentrić, M., Helland, K., & Arstorp, A.-T. (2017). *Professional digital competence framework for teachers*. The Norwegian Centre for ICT in Education. Retrieved May 2018, from https://iktsenteret.no/sites/iktsenteret.no/files/attachments/pfdk_framework_en_low.pdf

Lagrange, J. B., & Caliskan-Dedeoglu, N. (2009). Usages de la technologie dans des conditions ordinaires: le cas de la géométrie dynamique au collège. [The use of technology in ordinary conditions: the case of dynamic geometry in lower secondary education.] *Recherches en Didactique des Mathématiques, 29,* 189–226.

Lynch, D. R., Russell, J. S., Evans, J. C., & Sutterer, K. G. (2009). Beyond the cognitive: The affective domain, values, and the achievement of the vision. *Journal of Professional Issues in Engineering Education and Practice, 135*(1), 47–56.

MCEETYA. (2003). *A national framework for professional standards for teaching*. Ministerial Council on Education, Employment, Training and Youth Affairs, Australia. Retrieved May 2018, from http://www.curriculum.edu.au/verve/_resources/national_framework_file.pdf

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A new framework for teacher knowledge. *Teachers College Record, 108*(6), 1017–1054.

OECD. (2003). *The definition and selection of key competencies*. Executive summary. Retrieved May 2018, from https://www.oecd.org/pisa/35070367.pdf

Prensky, M. (2001). Digital natives, digital immigrants part 1. *On the Horizon, 9*(5), 1–6.

Redecker, C. (2017). *European framework for the digital competence of educators (DigCompEdu)*. Joint Research Centre Science for Policy Report. EU: Luxembourg Publications Office. Retrieved May 2018, from https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/european-framework-digital-competence-educators-digcompedu

Schoenfeld, A. H. (2011). Toward professional development for teachers grounded in a theory of decision making. *ZDM Mathematics Education, 43*(4), 457–469.

Strategy Development Group (2015). *Digital strategy for schools 2015–2020. Enhancing teaching, learning and assessment*. Retrieved April 2018, from https://www.education.ie/en/Schools-Colleges/Information/Information-Communications-Technology-ICT-in-Schools/Digital-Strategy-for-Schools/

Tabach, M., & Trgalová, J. (2017). In search for standards: Teaching mathematics in a technological environment. In G. Aldon & J. Trgalová (Eds.), *Proceedings of the 13th international conference on technology in mathematics teaching* (ICTMT13) (pp. 293–300). Lyon, France. Retrieved November 2017, from https://ictmt13.sciencesconf.org/data/pages/proceedings_compressed.pdf

Tabach, M., & Trgalová, J. (2019, in press). Knowledge and skills mathematics teachers need for ICT integration: The issue of standards. In G. Aldon & J. Trgalová (Eds.), *Technology to teach, learn and assess mathematics: Featuring extended selected papers of ICTMT 13*. Cham, Switzerland Springer.

Thomas, M. O. J., & Hong, Y. Y. (2005). Teacher factors in integration of graphic calculators into mathematics learning. In H. L. Chick & J. L. Vincent (Eds.), *Proceedings of the 29th conference of the international group for the psychology of mathematics education* (Vol. 4, pp. 257–264). Melbourne, Australia: University of Melbourne.

Thomas, M. O. J., & Palmer, J. M. (2014). Teaching with digital technology: Obstacles and opportunities. In A. Clark-Wilson et al. (Eds.), *The mathematics teacher in the digital era. An international perspective on technology focused professional development* (pp. 71–89). https://doi.org/10.1007/978-94-007-4638-1_4

Trgalová, J., & Tabach, M. (2018). In search for standards: Teaching mathematics in technological environment. In L. Ball, P. Drijvers, S. Ladel, H.-S. Siller, M. Tabach, & C. Vale (Eds.), *Uses of technology in primary and secondary mathematics education* (pp. 387–397). Cham, Switzerland: Springer.

Trouche, L., Gueudet, G., & Pepin, B. (2018). Open educational resources: A chance for opening mathematics teachers' resource systems? In L. Fan, L. Trouche, C. Qi, S. Rezat, & J. Visnovska (Eds.), *Research on mathematics textbooks and teachers' resources: Advances and issues*. Cham, Switzerland: Springer.

UNESCO. (2011). *ICT competency framework for teachers*. Paris, France: United Nations Educational, Scientific and Cultural Organization and Microsoft. Retrieved December 2017, from http://unesdoc.unesco.org/images/0021/002134/213475e.pdf

Voogt, J., Fisser, P., Pareja Roblin, N., Tondeur, J., & van Braak, J. (2012). Technological pedagogical content knowledge – A review of the literature. *Journal of Computer Assisted Learning, 29*(2), 109–206. https://doi.org/10.1111/j.1365-2729.2012.00487.x

Dr. Michal Tabach is an associate professor of mathematics education at Tel-Aviv University. She is currently the Head of Department of Education in Mathematics, Science and Technology. Her main lines of study involves learning and teaching in digital environment; how does learning evolves across different settings in the class: individuals, small groups and the whole class community; how can we encourage teachers to facilitate students learning vie argumentative base discussions.

Dr. Jana Trgalová is Associate Professor at Claude Bernard University in Lyon, France since 2003. She is involved in primary and secondary mathematics teacher education. Her research focuses on digital technology and resources for mathematics education, their design, appropriation, use and evaluation. She was involved in several national and international research projects and is active in the international research community in the field of technology in mathematics education.

Technology in Mathematics Teacher Education on Trust and Pitfalls

Rina Zazkis

1 Introduction

As mathematics teachers are adopting various forms of digital technologies in their teaching, their knowledge of using technology to advance pedagogy and support student learning becomes a focus of research attention. Acknowledging the influence of technology in teaching and learning of mathematics, the Association of Mathematics Teacher Educators (AMTE) (2009) suggested a Mathematics Technological Pedagogical and Content Knowledge (Mathematics-TPACK) framework. The TPACK framework relies on previous work of Mishra and Koehler (2006) and Koehler and Mishra (2009), and their general TPCK (Technological Pedagogical and Content Knowledge) framework, and extends it, highlighting the intersections among different types of knowledge and their particular links to Mathematics.

Both TPCK and Mathematics-TPACK frameworks are based on the traditional Pedagogical Content Knowledge (PCK) construct (Shulman, 1986), elaborating on how various aspects of knowledge are affected by technology. In AMTE (2009), it is emphasized that TPACK addresses the three “core” components of teacher knowledge (i.e., content, pedagogy, and technology), focusing on the interaction among them. In relation to teaching and learning mathematics, TPACK attends to teachers’ understanding of how students learn mathematics and the impact of technological tools on enhancing teaching and improving learning.

However, with wide availability of easily accessible information and computational tools often comes a blind trust in the reliability and accuracy of the accessed information and unquestioned dependence on it. In this chapter, I focus on pitfalls in understanding mathematics associated with the use of technology. In what follows (Sects. 4 and 5) I share examples in which the information accessed, or

---

R. Zazkis (✉)
Faculty of Education, Simon Fraser University, Burnaby, BC, Canada
e-mail: zazkis@sfu.ca

Y. Ben-David Kolikant et al. (eds.), *STEM Teachers and Teaching in the Digital Era*, https://doi.org/10.1007/978-3-030-29396-3_13

conclusions derived by teachers using technology, were either incorrect or incomplete and therefore misleading. In order to situate these examples, I briefly describe and exemplify the notion of fidelity (Sects. 2 and 3) as related to the educational uses of digital technologies in mathematics. In conclusion (Sect. 6) I discuss implications for teacher education.

2 On the Notion of Fidelity

Dick (2007) introduced the notion of *fidelity* associated with the use of technology in mathematics education. Aiming his discussion at the designers of technological tools for learning mathematics, he distinguished between mathematical fidelity, cognitive fidelity and pedagogical fidelity.

According to Dick (2007), pedagogical fidelity of a tool refers to a learner's interaction with mathematics, such as ability to create and manipulate mathematical objects and being presented with the consequences of these manipulations. Cognitive fidelity refers to whether a tool is faithful to students' cognitive processes, that is, whether concept is better understood when the tool is acted upon. Cognitive fidelity enables one to make connections by seeing developing patterns via interactive manipulation (Bos, 2009a, 2009b).

Mathematical fidelity – which is the focus of this paper – refers to the conformity of a technological tool with mathematical accuracy, that is, with mathematics as it is understood by a mathematical community. While the idea appears obvious, it can be difficult to implement due to technological limitations. Among the main problems related to mathematical fidelity are truncated/rounded display of computed results and issues associated with modeling a continuous phenomenon with discrete structures (Zbiek, Heid, Blume, & Dick, 2007). For example, when the result of division of 23 by 7 is displayed on a calculator screen as 3.28571429, a learner may assume that this is a correct quotient, rather than a truncated rounded representation of a repeating decimal fraction. (The correct result is $3.\overline{285714}$, that is, decimal representation with infinite repeating cycle of 6 digits.)

In particular, research that attended to mathematical fidelity focused on graphing calculators and described potential incorrect conclusions based on the displayed information (e.g., Zbiek et al., 2007). Restricted window display, plotting points that do not belong to the domain of a function, and precision limitations are among the features of graphing calculators that may lead to misinterpreting the intended mathematical features of functions.

3 Examples of "Infidelity"

In this section, I describe two examples of the lack of mathematical fidelity: one is the result of rounding, while the other is the result of programmers' choices.

3.1 "Counterexample" to Fermat's Last Theorem

Most scientific calculators will confirm that $3987^{12} + 4365^{12} = 4472^{12}$.

This "equality" is one of the hoaxes that seemingly dispute the famous Fermat Last Theorem. (The theorem claims that there is no positive integer values a, b, c that satisfy the equation $a^n + b^n = c^n$ for an integer value of $n > 2$).

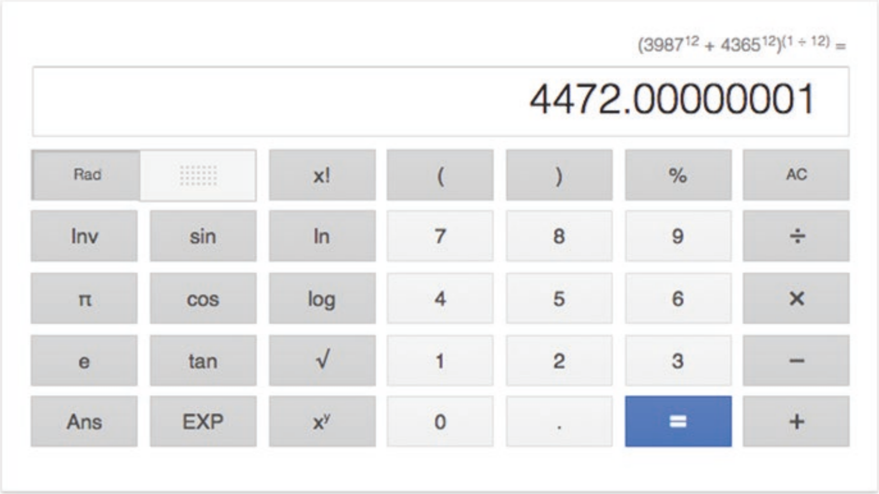
However, with more advanced computational abilities, the mystery of perceived counterexample disappears, as demonstrated in Fig. 1, where the twelfth root of $3987^{12} + 4365^{12}$ is displayed as 4472.00000001.

3.2 Division by Zero

Division by zero is a cause of many pitfalls and is known as a troublesome topic in mathematics (Thanheiser, Whitacre, & Roy, 2014). Calculators offer no help and possibly reinforce misunderstandings related to division by zero.

Figure 2 displays the result of 3 divided by zero on (a) calculator found on MacBook dashboard (b) system application Calculator, and (c) Google web-based calculator (respectively displaying messages such as "error", "not a number", and "infinity"). While this information is inconsistent and confusing, it is also in discord with a mathematical convention, where division by zero is undefined.

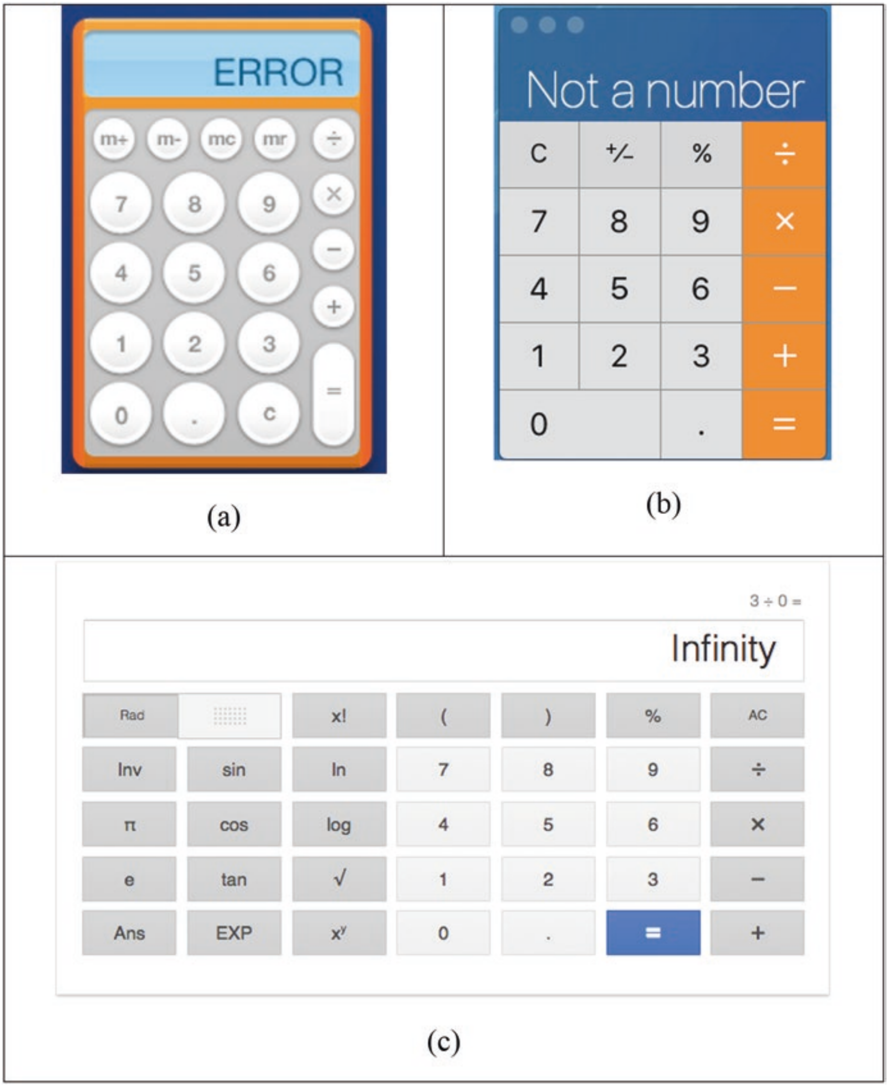
Siri (Apple's personal virtual assistant on iPhones and iPads) "knows" the correct answer, but the appropriate choice of the programmer, displaying $3 \div 0$ as "undefined", is infused with unnecessary supplemental information (see Fig. 3).



$(3987^{12} + 4365^{12})^{(1 \div 12)} =$

4472.00000001

Fig. 1 Disputing the equality $3987^{12} + 4365^{12} = 4472^{12}$

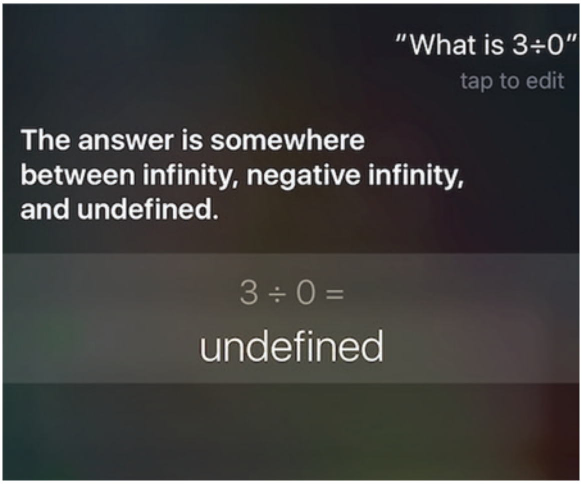


(a) (b) (c)

Fig. 2 Results of division by zero on different calculators

The lack of mathematical fidelity resulting from programming choices may be easier to fix as, unlike the precision of calculation, it does not depend on technological advances in hardware design. However, it is also less expected and therefore may not be detected by a trusting and unsuspicious user.

In what follows, I describe the same two cases of lack of mathematical fidelity – one resulting from a truncated calculator display and another from a programmer's choices – as (mis)interpreted by teachers. Both occurrences appeared in teachers' responses to a scripting task. As such, I introduce briefly the notion of script writing and scripting tasks.



"What is 3÷0"

The answer is somewhere between infinity, negative infinity, and undefined.

3 ÷ 0 =

undefined

Fig. 3 Screenshot from iPhone, Siri's response to division by zero

4 Settings: Script Writing

Script-writing is a (relatively) novel pedagogical and research approach. Zazkis, Sinclair, and Liljedahl (2013) have introduced and developed this approach in the context of mathematics teacher education (see also Zazkis, Liljedahl, & Sinclair, 2009). In the initial implementation, script-writing was referred to as "Lesson Play," describing imagined interaction between a teacher and students. It was juxtaposed with a "lesson plan," and described as a tool used in preparing for instruction. In the more recent implementation, the scope of this method was broadened where script-writing describes a hypothetical interaction among characters—that is, not restricted to a "lesson."

In the script-writing (or scripting) approach teachers are presented with a prompt that describes a problematic situation, a disagreement, a student error, or an inappropriate reasoning. The script-writing task is to devise a dialogue between the characters, who are students, or a teacher and students, that leads to a resolution. The scripts serve as research data and as springboards for consequent in-class discussions. We refer to scripting as a form of role-playing in one's imagination.

Script-writing was used in a variety of studies (e.g., Koichu & Zazkis, 2013; Kontorovich & Zazkis, 2016; Zazkis, 2014; Zazkis & Kontorovich, 2016) and the affordances of this approach for script writers (i.e., students or prospective teachers), for teacher educators and for researchers were detailed. In particular, for teachers, writing a script is an opportunity to examine personal response to a situation, explore erroneous or incomplete approaches of a student, revisit and possibly enhance personal understanding of the mathematics involved and enrich repertoire of potential responses to be used in the future "real" teaching. For teacher educators, the scripts provide a lens on planned pedagogical and mathematical approaches that can be consequently highlighted and discussed in working with teachers. For researchers, the scripts form a rich data source that can be examined from various perspectives, they provide a lens for examining how teaching is envisioned, and provide insights into the script-writers' understanding of mathematics (Zazkis et al., 2013).

Occasionally, the scripts highlight the perceived role of technology in instructional setting. In what follows, I describe several instances in which the created dialogue revealed a script-writer's reliance on technology. In particular, I describe examples from two script-writing tasks in which the assumed fidelity of technology contributed to an incorrect conclusion that was accepted by the characters involved in the dialogue, and that further served as a springboard for a subsequent class discussion.

4.1 *Example 1: Decimal Expansion of a Fraction*

In their scripting assignment, prospective elementary school teachers were presented a scenario in which interlocutors disagree on whether 23/43 is a rational or an irrational number (Zazkis & Zazkis, 2014). Some students relied on a calculator display, which showed no repeating pattern. This led to a conclusion that the number was irrational. The following excerpt exemplifies this conclusion.

S1: So, we get 0.53488372
S2: It looks irrational
S1: How do you know?
S2: To be rational it needs to be repeated, like we had 1/3 = 0.33333333
S1: But is it always the same digit?
S2: NO! Sometimes you get 2 or 3 repeated, or even more.
S1: But what if we had more digits, look, on this fancy calculator we get 0.534883720930233.
S2: And this only proved my point, do you see a repetition? NO. A rational number would go 123-123-123…. But this one goes random.
S1: So you are saying it is irrational.
S2: Obviously so.

As the excerpt shows, the "transparent" representation of a number as a ratio of two integers was insufficient in order to draw a conclusion. Instead, the conclusion was drawn based on the limited information on a calculator display. Actually, there are 21 digits in the unit of repeat in the infinite decimal representation of this number.

This erroneous interpretation of the partial result on a calculator was identified in prior research (e.g., Sirotic & Zazkis, 2007). Zazkis and Sirotic (2010) discussed the relationship between the definition of a rational number (as a ratio) and the resulting decimal expansion of a rational number. The lack of connection between the two representations, as featured in the responses of the participants, was identified as a "missing link." However, while the issue is familiar to mathematics educators from prior research and experience, the scripts provide an opportunity for the writers to express their beliefs explicitly. When it is expressed explicitly, there is an emergent opportunity for the teacher educator to address it, pointing to the definition of rational numbers as well as to the relationship between number representation as a fraction and its decimal representation.

In addition, directing prospective teachers' attention to the relationship between ratio and decimal representations naturally raises a question of, how many digits are there in the decimal expansion of a rational number? In my experience, there is a greater motivation for exploring this question after a personal pitfall in interpreting information on a calculator display is acknowledged.

4.2 Example 2: Sum of Exterior Angles in a Polygon

In their scripting assignment, secondary school teachers were asked to discuss the following claim: "The sum of exterior angles in a polygon is 360 degrees" (Kontorovich & Zazkis, 2016). As part of the scripted dialogue, teachers were invited to explore the scope of applicability of this claim and rephrase it where necessary. This followed the "Lakatosian tradition" after parts of the classical Lakatos' dialogue (Lakatos, 1976) were read and acted out in class. Similarly to the characters in Lakatos' dialogue, the characters created by teachers argued about the correctness of the claim, its possible extensions and refinements.

Note that the claim applies to convex polygons, but needs refinement for concave and self-intersecting polygons: in concave polygons the measure of some exterior angles is negative; in self-intersecting polygons the sum of the exterior angles is a multiple of 360°. See Fig. 4 for examples of (a) convex, (b) concave and (c) self-intersecting (crossed) pentagons.

In Kontorovich and Zazkis (2016) we analyzed students' conceptions of angle, whether it was perceived as a static shape or a dynamic turn. Teachers' reliance on available digital resources was not our focus of attention. However, we noted that most participants included in their scripts references to information accessed on the Internet and included screenshots from various applets. Excerpt A exemplifies such an attempt for accessing information. The part of the imaginary dialogue presented in Excerpt A takes place after student-characters considered both convex and concave polygons.

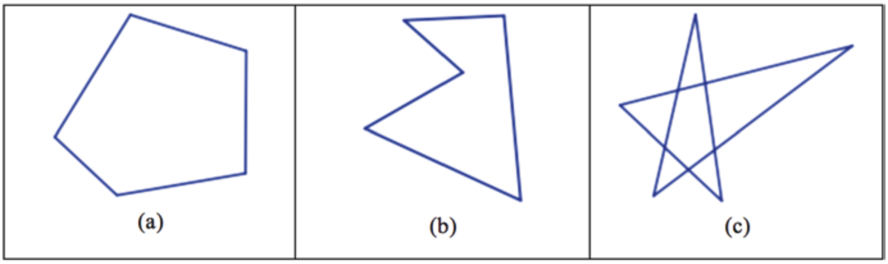


Fig. 4 Examples of pentagons: (**a**) convex, (**b**) concave and (**c**) self-intersecting

Excerpt A

S-B: But what about a polygon like this? (a drawing of self-intersecting polygon accompanied the script)
S-A: Is that a polygon? Are crossed polygons real polygons?
S-B: I seem to recall that lots of rules about polygons won't work if the polygon crosses over itself. And in this case, the exterior angles don't add up to 360°.
[…]
S-A: But how is that one considered a single polygon? It's really two polygons that share a vertex.
S-B: According to my fancy iPad and Wolfram MathWorld, "Polygons can be convex, concave or star." Is that right, teacher?
T: Since Pythagoreans' time, true polygons have included self-intersecting polygons.
S-C: But the Pythagoreans also didn't accept irrational numbers. Just because they had a certain definition of anything, doesn't mean it's still valid today, or that we must accept it.
S-B According to Wikipedia, "The most commonly accepted definition of a polygon in the mathematics community is a simple, closed figure, comprised of line segments joined pairwise at the endpoints, called vertices. This definition is what is used in any study of Euclidean geometry, as the results of that study rely upon this fact. Of course, there are likely to be people in other disciplines that do not agree with this definition, but the common standard is that what you call 'coptic' are not usually considered polygons."
S-B I suggest we go with Wikipedia and get over with it.

Kontorovich and Zazkis (2016) analyzed the tendency to restrict the example space of the considered polygons as establishing a need for certainty (Harel, 2008) in the conjecture and avoiding the possibility of extending the conjecture. Here I focus on the use of technology to access information and also to substantiate the desirable choices of example space.

This conversation demonstrates, in the voices of student-characters, that teachers-script-writers used a variety of web-based resources (Wolfram MathWorld, Wikipedia) to decide whether a "crossed polygon" was a "real polygon". It further demonstrates that the script-writer was not attentive to distinguishing a reliable web-based resource from a website that explains a personal perspective of the author. Being surprised with the cited "commonly accepted definition" from Wikipedia, we noted that the quote was taken from Wikipedia discussion volume (Talk: polygon, n.d.), which is, as the name suggests, a forum for discussion, rather than a reference for conventionally accepted definitions. However, Wikipedia article clearly includes self-intersecting polygons, where "the boundary of the polygon crosses itself" as a subset of polygons (Polygon, n.d.).

The next excerpt, Excerpt B, presents an explanation of how the measures of the angles in a concave polygon have to be calculated in order for the sum of the angles to result it 360 degrees.

Excerpt B

S-A: We measure a whole bunch of angles but the only way to make the exterior angles of concave polygons add to 360° was if we subtracted the angle that went inside. It works, but I don’t get why.

S-B: Oh, Oh, I think I know!! Originally, when we extended the sides of polygons to make exterior angles, they went outside, but at concave vertices, the extended side went inside the polygon—that’s opposite. When we extended sides outside the polygon, we added angle. So instead of adding, the angles that go inside, we have to subtract them.

T: What an excellent way of putting it. At this point, it appears that the exterior angles of concave polygons may also add to 360°. Many of you have questioned why this works and [S-B]’s reason helps. Thank you [S-B].

The explanation presented by student character was analyzed in Kontorovich and Zazkis (2016) in analogy to “intuitive rules” described by Stavy and Tirosh (2000). That is, the procedure “outside/ add – inside/ subtract” was implemented, without attention to the direction of the turn. However, rather than analyzing the student’s reasoning, my focus here is on the diagram that accompanied the script, see Fig. 5.

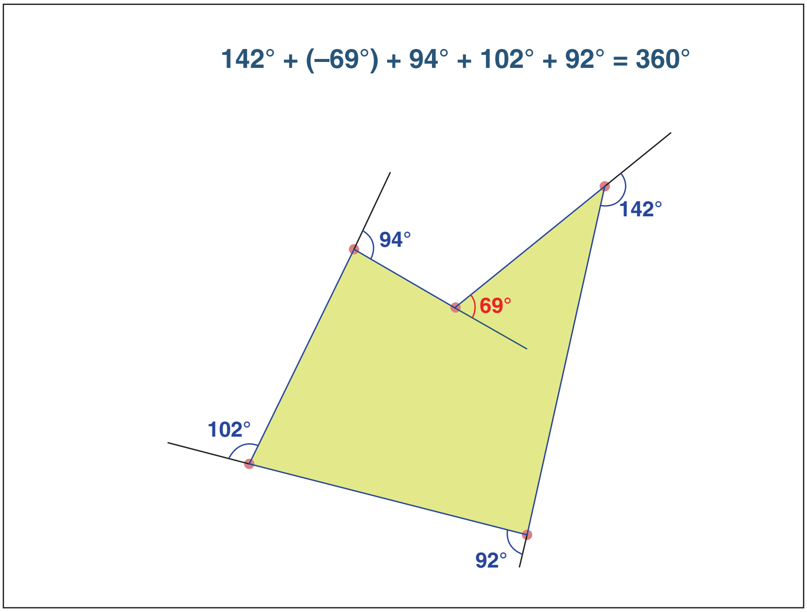


Fig. 5 Sum of the exterior angles in a concave polygon

Note the sum of the angles is claimed to be 360°, while the calculation actually results in 361°. Obviously, the script-writer trusted the presented calculation and did not care either to check it or to adjust the diagram so the displayed sum is correct.

The same website was used by another script-writer to explore the sum of the exterior angles in self-intersection, so-called “crossed” polygons. In the dialogue the student-characters explored various crossed polygons, confirmed the conjecture based on the applet-provided calculation, and the teacher-character reinforced the observation that this sum is always 360°.

Figure 6a accompanied the script; in Fig. 6b and c I adjusted the angles, to make the ridiculous claim of equality more obvious, without the need to calculate. Note that 0°, 720° or any other multiple of 360° is the sum of the exterior angles in a self-intersecting polygon.

While displaying 360° instead of 361° can be explained as a rounding error (as the angle measures displayed are whole numbers), showing the sum of 360° rather than correct sum of 0° or 720° points to a serious misconception of the programmer or site designer. It is clear that the number displayed to the right of the equal sign remains constant and does not correspond to the result of adding the angles. Unfortunately, this error was not detected by the script-writer and the mistake was reinforced by the teacher-character in the dialogue.

4.3 On the Power of Scripting

As mentioned previously, the scripts composed by (prospective) teachers provide a teacher educator with an overview of ideas held by the script-writers. Even without an explicit request, script-writers envision themselves in the role of the teacher-character. As such, they identify with the words and the chosen approaches of their character. When the scripted dialogue is between students, it is most often the case that one of the student-characters assumes the role of a teacher, or otherwise a “knowledgeable interlocutor.” So mistakes or inaccuracies of the teacher-character, as well as those of student-characters that are not corrected by the teacher, point to personal views of the script-writer.

These explicit expressions of ideas make the follow-up instruction more focused, attending to the ideas that surfaced in the scripts, which often do not only reinforce but also extend what has been described previously in research literature.

5 More on Rounding and Partial Information

Working with elementary school teachers on exploration of Fibonacci numbers, I heard a conclusion that “from the 8th place on, the ratio of two consecutive Fibonacci numbers is constant.” This was based on the information from a spreadsheet, where the number of digits in the decimal fraction was by default set to 2. Indeed, accord-

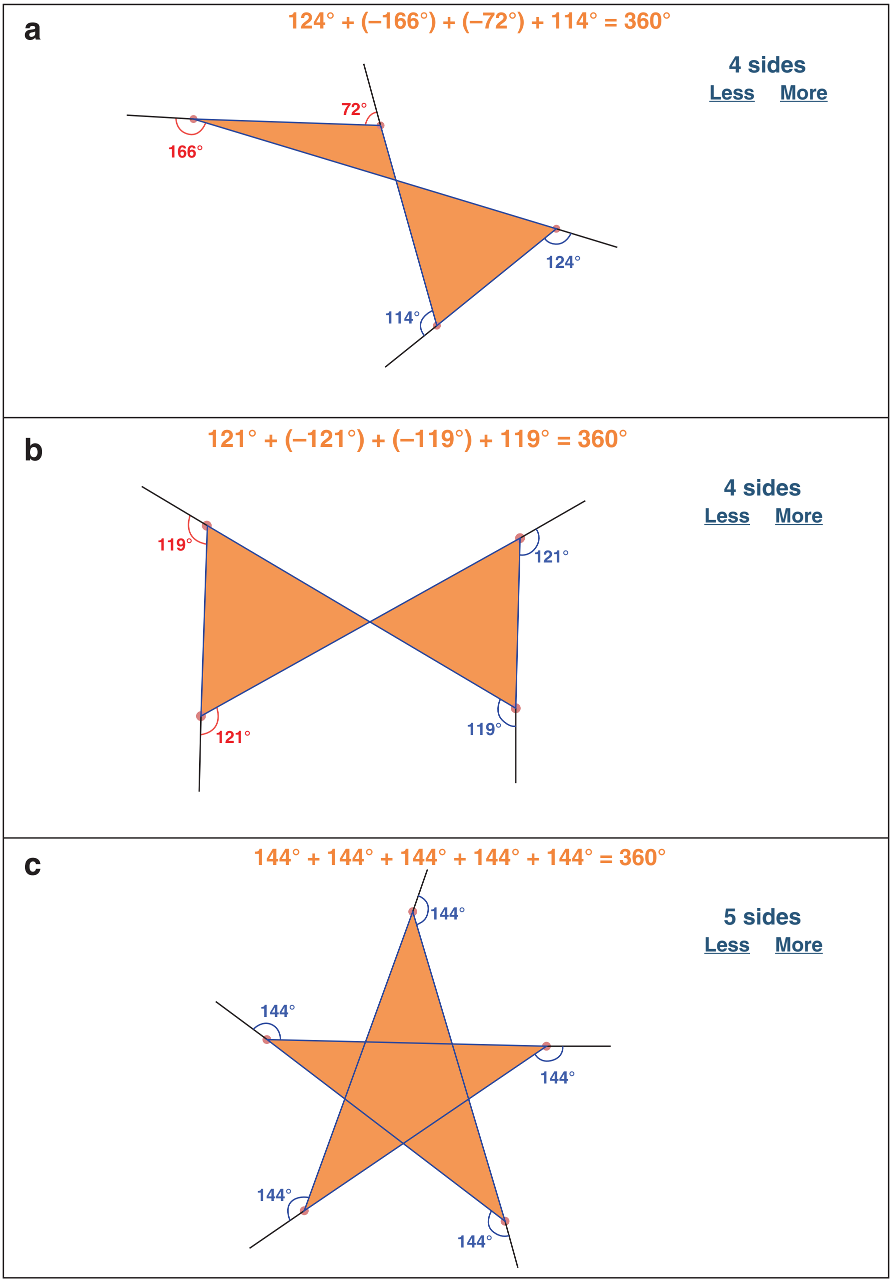


Fig. 6 Incorrectly displayed sum of the exterior angles in a self-intersecting polygon. Screenshots from http://www.mathopenref.com/polygonexteriorangles.html

ing to the information in the middle column of the spreadsheet (see Fig. 7) the ratio of 21 (the 8th Fibonacci Number) to 13 (the 7th Fibonacci number) is displayed as 1.62, and the same ratio is displayed for 34:21, 55:34, etc.

I asked students to use the option of showing more digits after the decimal point (see Fig. 7). Extending the displayed number of digits, the conclusion was rephrased: the ratio is constant from the 25th place.

The immediate response is to extend the number of displayed digits after the decimal point. However, as is seen on the right column of Fig. 7, while this may refute the conclusion of "constant ratio from the certain place", the display of "actual ratio" obscures the idea of limit, which is the intended conclusion from looking at consecutive ratios (Fig. 7).

I teach students to be skeptical of the information suggested by technology. However, recently I myself accepted such information exploring a problem in geometry with the Geometer's Sketchpad. The calculation provided by the computer program led to a particular assumption, and when the provided calculation disagreed with my conclusion I dismissed it as "rounding error."

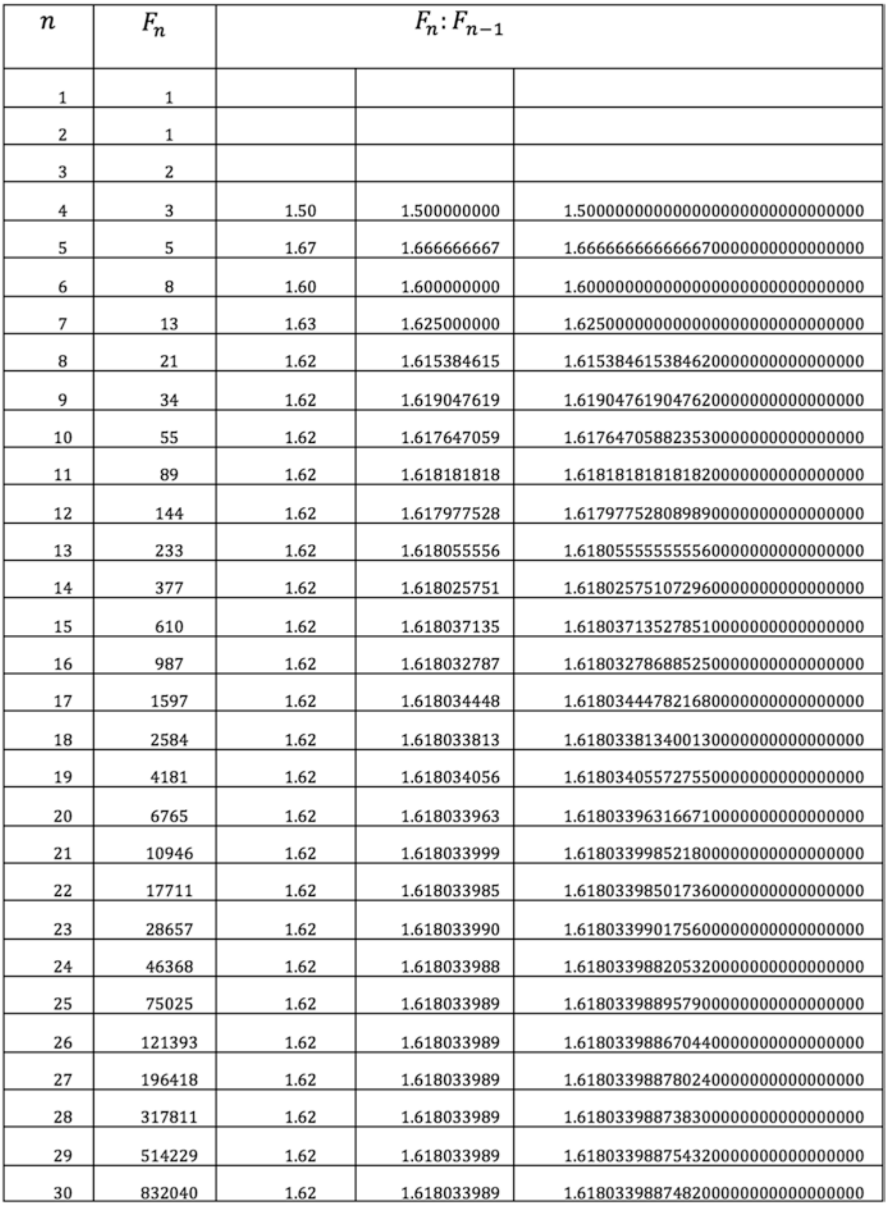
The particular problem invited the exploration of the ratio of areas of quadrilaterals ABCD and EFGH. As shown in Fig. 8, the quadrilateral EFGH (dark in the middle) results by connecting the vertices of ABCD to the midpoints of the opposite side. I was convinced that this ratio is 5, as indeed is the case when ABCD is a parallelogram. By dragging the vertices of ABCD, I looked at different quadrilaterals and confirmed my conclusion. When the displayed ratio differed from 5 (see Fig. 8d and c, where the displayed ratio is 5.1), I dismissed it as a "rounding error."

It was John Mason and Cinderella dynamic geometry software, in which (unlike the Geometer's Sketchpad that I use) it is possible to control the number of digits after the decimal point, that convinced me that 5.1 was not a result of the rounding error, but a rounding of a ratio like 5.13456. In fact, when one of the vertices of the 'outer' quadrilateral is dragged using Cinderella, the displayed ratio of areas changes slightly, sometimes only in the second or third digit after the decimal point. This led to an exciting exploration of the bounds of this ratio, and possible variations of the constructions. I will not spoil for the reader the pleasure of this exploration by disclosing our results. (Some results are found in Mason and Zazkis, 2019.)

6 Conclusion

Technological resources are an integral part of our lives, used to access information and to manipulate objects. Students and teachers alike rely on technological resources regardless of requirements of particular tasks. Even experienced mathematics educators can be misled by the available information or by the reasonable but incorrect interpretation.

Many issues related to fidelity of technology reported in research a decade ago are slowly disappearing. Consider for example implied multiplication. In order to graph $f(x) = 2x$, one needed to input explicitly 2∗x on a graphing calculator to indi-



n	F_n	$F_n : F_{n-1}$		
1	1			
2	1			
3	2			
4	3	1.50	1.500000000	1.500000000000000000000000000000
5	5	1.67	1.666666667	1.666666666666670000000000000000
6	8	1.60	1.600000000	1.600000000000000000000000000000
7	13	1.63	1.625000000	1.625000000000000000000000000000
8	21	1.62	1.615384615	1.615384615384620000000000000000
9	34	1.62	1.619047619	1.619047619047620000000000000000
10	55	1.62	1.617647059	1.617647058823530000000000000000
11	89	1.62	1.618181818	1.618181818181820000000000000000
12	144	1.62	1.617977528	1.617977528089890000000000000000
13	233	1.62	1.618055556	1.618055555555560000000000000000
14	377	1.62	1.618025751	1.618025751072960000000000000000
15	610	1.62	1.618037135	1.618037135278510000000000000000
16	987	1.62	1.618032787	1.618032786885250000000000000000
17	1597	1.62	1.618034448	1.618034447821680000000000000000
18	2584	1.62	1.618033813	1.618033813400130000000000000000
19	4181	1.62	1.618034056	1.618034055727550000000000000000
20	6765	1.62	1.618033963	1.618033963166710000000000000000
21	10946	1.62	1.618033999	1.618033998521800000000000000000
22	17711	1.62	1.618033985	1.618033985017360000000000000000
23	28657	1.62	1.618033990	1.618033990175600000000000000000
24	46368	1.62	1.618033988	1.618033988205320000000000000000
25	75025	1.62	1.618033989	1.618033988957900000000000000000
26	121393	1.62	1.618033989	1.618033988670440000000000000000
27	196418	1.62	1.618033989	1.618033988780240000000000000000
28	317811	1.62	1.618033989	1.618033988738300000000000000000
29	514229	1.62	1.618033989	1.618033988754320000000000000000
30	832040	1.62	1.618033989	1.618033988748200000000000000000

Fig. 7 Fibonacci numbers and consecutive ratios

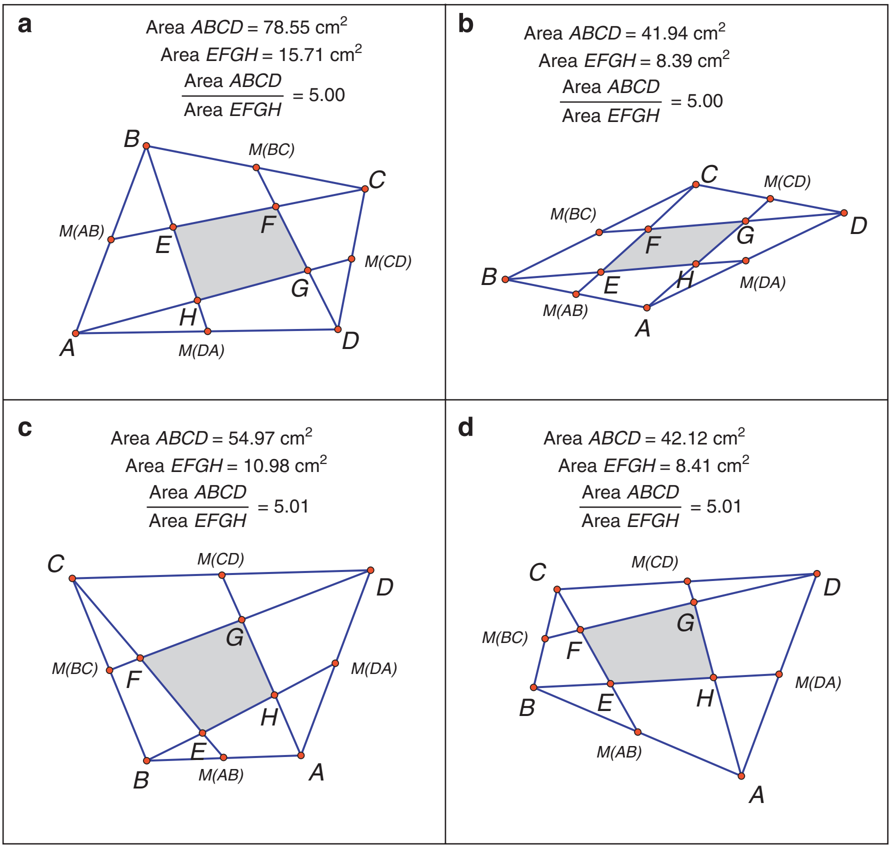


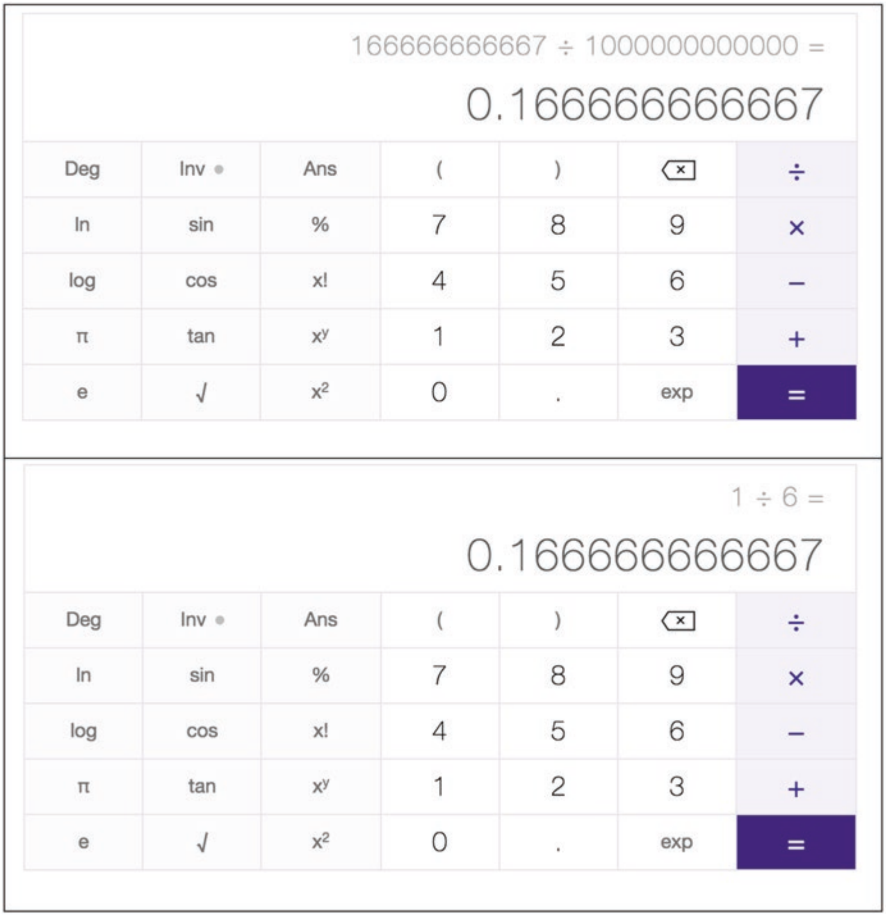
Fig. 8 Screen shots from Geometer's Sketchpad comparing areas of quadrilaterals

cate multiplication. However, more advanced graphing devices are able to interpret $2x$ as intended and even parse correctly expressions like "$sin2x$". Furthermore, issues associated with low resolution and limited window size on the screen of graphing calculators disappear with more advanced graphing tools.

However, issues related to mathematical fidelity of technology remain, of which I will focus on two. First, there are potential pitfalls associated with accuracy of displayed calculations. For example, a calculator displays the same answer for 166666666667 ÷ 1000000000000 and for 1 ÷ 6 (see Fig. 9). While the former is an accurate result, the latter is a rounding of an infinite decimal expansion.

I believe these are relatively easy to address, merely by pointing to the fact that the calculation is incomplete or rounded. Possibly, with technological advances the result of 1 ÷ 6 can be displayed as 0.166666666667(r) or 0.166666666667(≈), pointing to incomplete/rounded information.

The second issue is lack of fidelity in programmers' decision. In addition, the exponential growth of available and easily accessible information also increases the



166666666667 ÷ 1000000000000 =

0.166666666667

1 ÷ 6 =

0.166666666667

Fig. 9 Equal results of different calculations

amount of incorrect or incomplete information. Unlike the previous example, this problem cannot be handled with technological solutions. That is where a personal judgment of a teacher on the correctness and accuracy of the accessed or displayed information is essential. Olive et al. (2010) refer to the myth that calculator is never wrong. It appears that some teachers have extrapolated this myth to any information displayed on a computer application.

AMTE standards (2017) include the use of mathematical tools and technology among the indicators of knowledge of mathematics for teaching. In particular, it is essential that mathematics teachers recognize both pedagogical potential and limitation of technological tools. However, discussion on limitations in mathematics education literature focuses mainly on limitations associated with technological affordances. For example, Burrill (2017) suggested that mathematical fidelity of software is a leading principle in designing mathematical tasks for development of students' conceptual understanding. Furthermore, Leung and Baccaglini-Frank (2017) noted that whether a particular environment provides a potential or pitfall for learners is closely related to teachers' choices. In particular, they commented that "knowledge/meaning gaps may exist between digital-based mathematical discourses and the intended mathematical content. Potential can become a pitfall or vice versa depending on the ways in which the teacher handles this gap." (ibid, p. x).

Further to these suggestions, I argue that further attention should be given in teacher education to potential pitfalls associated with lack of mathematical fidelity, which is a result of programming choices. Identifying discrepancy between formal mathematics and what can be mistakenly concluded relying on a digital tool can be turned to an educational opportunity. In addition, teachers' attention should be explicitly directed towards identifying reliable sources of digitally accessible information.

References

Association of Mathematics Teacher Educators. (2009). *Mathematics TPACK (Technological Pedagogical Content Knowledge) Framework*. Retrieved Dec 1, 2017 from https://amte.net/sites/all/themes/amte/resources/MathTPACKFramework.pdf

Association of Mathematics Teacher Educators. (2017). *Standards for preparing teachers of mathematics*. Available online at amte.net/standards. Retrieved December 1, 2017 from https://amte.net/sptm

Bos, B. (2009a). Virtual math objects with pedagogical, mathematical, and cognitive fidelity. *Computers in Human Behavior, 25*(2), 521–528.

Bos, B. (2009b). Technology with cognitive and mathematical fidelity: What it means for the math classroom. *Computers in the Schools, 26*(2), 107–114.

Burrill, G. (2017). Designing interactive dynamic technology activities to support the development of conceptual understanding. In A. Leung & A. Baccaglini-Frank (Eds.), *Digital technologies in designing mathematics education tasks: Potential and pitfalls* (pp. 303–328). Cham, Switzerland: Springer.

Dick, T. P. (2007). Keeping the faith, fidelity in technological tools for mathematics education. In G. W. Blume & M. K. Heid (Eds.), *Research on technology and the teaching and learning of mathematics: Vol. 2. Cases and perspectives* (pp. 333–339). Charlotte, NC: Information Age.

Harel, G. (2008). *DNR perspective on mathematics curriculum and instruction, part II* (Vol. 40, pp. 893–907). Zentralblatt für Didaktikder Mathematik.

Koehler, M. J., & Mishra, P. (2009). What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education, 9*(1). Retrieved July 8, 2017 from http://www.citejournal.org/vol9/iss1/general/article1.cfm

Koichu, B., & Zazkis, R. (2013). Decoding a proof of Fermat's Little Theorem via script writing. *Journal of Mathematical Behavior, 32*, 364–376.

Kontorovich, I., & Zazkis, R. (2016). Turn vs. shape: Teachers cope with incompatible perspectives on angle. *Educational Studies in Mathematics, 93*(2), 223–243.

Lakatos, I. (1976). *Proofs and refutations*. Cambridge, MA: Cambridge University Press.

Leung, A., & Baccaglini-Frank, A. (2017). Introduction. In A. Leung & A. Baccaglini-Frank (Eds.), *Digital technologies in designing mathematics education tasks: Potential and pitfalls* (pp. vii–xvi). Cham, Switzerland: Springer.

Mason, J., & Zazkis, R. (2019, online first). Fooled by rounding. *Digital Experiences in Mathematics Education*.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for integrating technology in teacher knowledge. *Teachers College Record, 108*(6), 1017–1054.

Olive, J., Makar, K., Hoyos, V., Kor, L., Kosheleva, O., & Strässer. (2010). Mathematical knowledge and practices resulting from access to digital technologies. In C. Hoyles & J. Lagrange (Eds.), *Mathematics education and technology – Rethinking the terrain (the 17th ICMI study)* (pp. 133–178). New York, NY: Springer.

Polygon. (n.d.). *In Wikipedia*. Retrieved December 2, 2017, from http://en.wikipedia.org/wiki/Polygon

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.

Sirotic, N., & Zazkis, R. (2007). Irrational numbers: The gap between formal and intuitive knowledge. *Educational Studies in Mathematics, 65*(1), 49–76.

Stavy, R., & Tirosh, D. (2000). *How students (mis-)understand science and mathematics: Intuitive rules*. NewYork, NY: Teachers College Press.

Talk: polygon. (n.d.). *In Wikipedia*. Retrieved December 13 2014, from http://en.wikipedia.org/wiki/Talk:Polygon

Thanheiser, E., Whitacre, I., & Roy, G. J. (2014). Mathematical content knowledge for teaching elementary mathematics: A Focus on whole-number concepts and operations. *The Mathematics Enthusiast, 11*(2), 217.

Zazkis, D. (2014). Proof-scripts as a lens for exploring students' understanding of odd/even functions. *Journal of Mathematical Behavior, 35*, 31–43.

Zazkis, R., & Kontorovich, I. (2016). A curious case of superscript (-1): Prospective secondary mathematics teachers explain. *Journal of Mathematical Behavior, 43*, 98–110.

Zazkis, R., Sinclair, N., & Liljedahl, P. (2013). *Lesson play in mathematics education: A tool for research and professional development*. Dordrecht, The Netherlands: Springer.

Zazkis, R., & Sirotic, N. (2010). Representing and defining irrational numbers: Exposing the missing link. *Research in Collegiate Mathematics Education, 7*, 1–27.

Zazkis, R., & Zazkis, D. (2014). Script writing in the mathematics classroom: Imaginary conversations on the structure of numbers. *Research in Mathematics Education, 16*(1), 54–70.

Zazkis, R., Liljedahl, P. & Sinclair, N. (2009). Lesson Plays: Planning teaching vs. teaching planning. *For the Learning of Mathematics, 29*(1), 40–47.

Zbiek, R. M., Heid, M. K., Blume, G. W., & Dick, T. P. (2007). Research on technology in mathematics education: A perspective of constructs. In F. K. Lester (Ed.), *Second handbook of research on mathematics teaching and learning* (pp. 1169–1207). Charlotte, NC: Information Age.

Rina Zazkis is a Professor of Mathematics Education at the Faculty of Education and associate member in the Department of Mathematics at the Simon Fraser University, Canada, where she has been employed since 1991. Her research is in the area of undergraduate mathematics education, with a general focus on mathematical content knowledge of teachers and the ways in which this knowledge is acquired and modified. For 9 years (2007–2015) she served as an editor responsible for mathematics of the Canadian Journal of Mathematics, Science and Technology Education. She is currently an associate editor of the Journal of Mathematical Behavior. In her career she supervised numerous graduate students and received an award for excellence in graduate supervision. In 2016 Zazkis was appointed as Tier 1 Canada Research Chair, a prestigious recognition of excellence in research and research training.

Emergent STEM Teaching Possibilities in an Era of Educational Technologies

Shulamit Kapon

1 Introduction

This essay discusses three chapters in this volume: (1) Technology in mathematics teacher education: On trust and pitfalls, by Rina Zazkis; (2) Teaching mathematics in the digital era: Standards and beyond, by Michal Tabach and Jana Trgalová; and (3) Deliberate pedagogical thinking with technology in STEM teacher education, by Marina Milner-Bolotin. These three chapters provide complementary examinations of the role of teachers in the productive integration of information and communication technologies (ICT) into schools, and its implications for teacher education. Tabach and Trgalová (in this volume) compare and contrast various national and international standards for teaching with ICT, and focus on their implications for mathematics education. They infer dimensions of professional knowledge and skills that afford productive instructional use of ICT in mathematics education. Milner-Bolotin (in this volume) examines how technology-enhanced pedagogies can be productively integrated into instruction, through innovative STEM teacher education, while Zazkis (in this volume) examines the specific pitfalls of the inevitable infusion of ICT into mathematics education.

This chapter aims to highlight and elaborate on crosscutting themes in these chapters: (1) technology provides different forms of doing; (2) the intrinsic and instructional affordances of technology; (3) appropriating ICT for instruction; (4) teachers' professional knowledge; (5) implications for teacher education.

S. Kapon (✉)
Faculty of Education in Science and Technology, Technion – Israel Institute of Technology, Haifa, Israel
e-mail: skapon@technion.ac.il

Y. Ben-David Kolikant et al. (eds.), *STEM Teachers and Teaching in the Digital Era*, https://doi.org/10.1007/978-3-030-29396-3_14

2 Technology Provides Different Forms of Doing

While not stated explicitly, all three authors implicitly acknowledge that availability of ICT and its use in teaching has drastically changed the nature of the tasks and learning activities students are engaged in. Zazkis (in this volume) and Milner-Bolotin (in this volume) provide specific examples of these novel tasks and learning activities.

These are indeed different forms of doing, since not only the nature of the tasks has changed with the infusion of ICT, but the cognitive activity of the learners has changed as well. Cognitive science deals with mental representations of knowledge, the processes that use these representations to achieve goals (e.g., problem solving), and the processes that change these representations. An underlying assumption was initially that all the processes involved take place in the individual mind. Edwin Huchins (1995, 2006) challenged this assumption. He suggested that real-life problem-solving take place in social systems that are often composed of several individuals who work with a suite of technological devices that shape the nature of the cognitive activity. He conceptualized the ad-hoc system of people and tools collaboratively involved in the performance of a particular task as a cognitive system, where unique system-specific knowledge representations are stored rather than in the individual mind. Problem solving, according to this view, take place through a manipulation of system-specific knowledge representations, and these representations and inscriptions are shaped by the available tools (Stevens & Hall, 1998). Hence, from this perspective, the unit of analysis is determined by the nature of the task, and includes the people and tools that form the distributed cognition system. In my view, the distributed cognition in systems that involve ICT forms the essence of what Milner-Bolotin (in this volume) refers to as “technology as a partner,” the ultimate competency in using the technology that Tabach and Trgalová (in this volume) call for, and what shapes the pitfalls that Zazkis (in this volume) highlights. In the following paragraphs I discuss this claim.

Elaborating on how a system of people and tools can be modeled as a cognitive system in problem solving (i.e., distributed cognition), Hutchins (1995, 2006) argued that technological tools often serve as means to off-load our cognition into the environment, and as extensions to our minds (Hutchins, 2006). We off-load memory to the environment, for example, by writing notes. We also off-load calculations to the environment. Consider Zazkis’ (in this volume) example of students reasoning through the problem of Fibonacci numbers (Zazkis, in this volume, Fig. 7) or the various (mis)use of calculators by her students. The calculations were made by the tool, and were stored on it. The students interpreted (or misinterpreted) the results. We also off-load memory in the form of visualizations. Zazkis’ description of the use of the Geometer’s Sketchpad (Zazkis, in this volume, Fig. 8) illustrate such off-loads.

The point is that the availability of ICT tools has a direct effect on the level and nature of problem solving that people can engage in, and the reasoning processes that are entailed. People are able to solve far more complex problems today using technology than they could in the past. Graphical calculators such as Desmos or Wolfram Alpha and numerical computing environments such as Excel or Matlab allow STEM students to solve problems that are far beyond their formal mathematical knowledge and skills. The availability of GPS and navigating applets such as Waze and Google-Maps allow people who do not know almost anything about navigation to independently find their way in unknown locations. The availability of environments for statistical analysis such as SPSS allow social science students to conduct complex statistical analyses without an in-depth understanding of the mathematical underpinning that drives these analyses.

The cognitive functions and processes used to solve problems change radically as a function of the use of different technologies. The representations of information and how they are transformed, combined, and propagated through our cognitive system depend considerably on the tools we are using. Take for example the cognitive activity involved in finding the results of the division of 473 by 4 when we solve this exercise in our minds, as opposed to when we solve it using paper and pencil to do long division, or when we use a calculator to solve it. Another example is the problem of navigating from one place to another with a map and a compass, as opposed to doing so with a personal navigation assistant such as the Waze application (Fig. 1). Although the final outcome is (successfully) getting from one place to another, cognitively we are doing very different things. Our grasp of the environment and the features to which we are attentive is different, the inscriptions we are sensitive to are different, and the information that we off-load to the tool are different. All these lead to a different cognitive process of navigation. Zazkis (in this volume) highlighted the problematic results of an examination of the validity of a mathematical claim using graphical calculators. Note that the cognitive processes involved in this investigation are very different from the ones involved in investigating the same problem with formal mathematics tools.

Zaskis (in this volume) showed that people put their blind trust in the technology, and presents very interesting cases of the "infidelity" of the technology. Some of the consequences of this infidelity stem from the different cognitive processes involved

Fig. 1 Navigation with a map and compass vs. navigation with personal navigation assistant (The source of the left picture in Fig. 1 is: https://pixabay.com/en/compass-bearing-compass-navigation-3072376/ under CC0 license (https://creativecommons.org/publicdomain/zero/1.0/). The source of the right picture in Fig. 1 is: https://en.wikipedia.org/wiki/GPS_navigation_device#/media/File:Garmin_N%C3%BCvi_200.jpg under CC BY-SA 3.0 license (https://creativecommons.org/licenses/by-sa/3.0/)

in using formal mathematics to solve a problem, as compared to solving it numerically with available technological tools. Each tool, whether a formal mathematics procedure, or a technological tool, has different affordances and constraints. Zazkis concludes that teachers need to be taught to become skeptical of the technology. I would argue that this is not a question of always being skeptical but rather one of understanding the affordances and constraints of the tool, as well as the contexts, conditions and purposes in which it is wise to use it, and how to efficiently use it. In my view, this is the essence of Tabach's and Trgalová's (in this volume) call for teachers' understanding of the "personal instrumental genesis" of the technology they employ in their classrooms, which I elaborate on below.

3 Identifying the Affordances (and Constraints) of ICT

The concept of affordance emerged in ecological psychology. Gibson (1986) defined an affordance as a property of an object in the environment that reflect conditions or constraints to which we are attuned. The affordances of an object, in this view, determine the kind of interaction that people can have with the object. For example, consider the wooden chair in Fig. 2. Its shape invites us to sit on the seat rather than on its back rest. In the same manner, different ICT applications have different affordances. Consider some of the specific examples of ICT discussed by Zazkis (in this volume) and Milner Bolotin (in this volume). Milner-Bolotin describes her implementation of an online collaborative platform (Collaborative Learning Annotation System – CLAS) in the STEM teacher education program at the University of British Colombia. CLAS allows users to upload and share video files, as well as add general or time-specific comments to the stored videos, respond to other members' comments and generate discussion threads. When Milner-Bolotin (in this volume) explains the rationale for employing CLAS she is describing the instructional

Fig. 2 The affordances of a chair. (Source: http://www.freestockphotos.biz/stockphoto/9530. Under CC0 license https://creativecommons.org/publicdomain/zero/1.0/)

affordances she realized were available in CLAS, such as the possibilities for reflections and online collaborative learning, or the documentation of learners' progress. Her course design capitalized and built on these affordances. Zazkis (in this volume) describes students who chose to use an available geometry application to investigate the statement that "the sum of exterior angles in a polygon is 360 degrees." Zazkis points out a problematic programming error in the application on the part of the designer that leads to a ridiculous mathematical mistake. She reports how her students, future mathematics teachers, were completely unaware of the mistake because of their blind trust in the technology. Clearly, the specific application was problematic. But what this case highlights is the way the students approached the problem as a direct result of their access to the online application. What the geometry application afforded is a concrete visualization and manipulation of the geometric shapes, and an immediate calculation of the sum of the angles (although it was incorrect, which the students did not know). Hence, instead of engaging in formal abstract thinking, the students were naturally drawn to the more intuitive concrete way of approaching the problem afforded by the tool. Note that that this is not an instructional affordance but rather an intrinsic affordance of the tool. Note also that when solving the problem in this way the cognitive process involved is very different from solving it with formal mathematical tools.

There is often a difference between the intrinsic affordances of a tool and its instructional affordances. For example, Zazkis (in this volume) describes an instructional affordance that stems from one drawback of calculators; namely, the limited number of decimal digits of the result:

> directing prospective teachers' attention to the relationship between ratio and decimal representations naturally raises a question of, how many digits are there in the decimal expansion of a rational number?. In my experience, there is a greater motivation for exploring this question after a personal pitfall in interpreting information on a calculator display is acknowledged.

Objects are not necessarily physical, and not all affordances are visible. Greeno (1994), who discussed educational affordances, argued that some affordances can be perceived directly when we interact with the environment, whereas others can only be noticed after learning. Such affordances are only recognized as features of an object when they match stored patterns; i.e., a knowledge representation. Milner-Bolotin (in this volume), Zazkis (in this volume) and Tabach and Trgalová (in this volume) emphasize the pivotal role of teachers' knowledge in productive implementations of ICT in their classroom. The ability to recognize the affordances and constraints of a specific technology as well as its instructional affordances is informed by this knowledge.

Tabach and Trgalová (in this volume) conceptualize the difference between identifying the intrinsic affordances of a technology and its instructional affordances in different terms. Building on work in mathematics education (Haspekian, 2011; Rabardel, 2002), they argue that a user develops an instrument from an artefact (i.e., the ICT tool) to accomplish a given (mathematical) task. This process is termed instrumental genesis. Tabach and Trgalová (in this volume) differentiate between two instrumental geneses. Personal instrumental genesis reflects the awareness and understanding of how the ICT tool can be used to solve the problems it was designed to solve (in their case, a mathematical problem). Professional instrumental genesis reflects the awareness and understanding of how an ICT tool can be used to teach something (in their case, a topic in mathematics). Consider for example the Excel spreadsheet application. As a spreadsheet, Excel was originally designed to be an interactive computer application for organizing, analyzing and storing data. Understanding and knowing how to use the program for this purpose reflects the personal instrumental genesis of Excel. However, teachers can use Excel for instructional purposes, such as explaining the fundamentals of numerical modelling in physics, or creating a dynamic graphical representation. Such uses reflect a professional instrumental genesis of Excel. In the same manner, we can use the statistical software SPSS to analyze data in statistics (i.e., personal instrumental genesis), but we can also use SPSS in specific ways to teach statistics (i.e., professional instrumental genesis). In the first case our interaction with the ICT tool is determined by the ICT tool's intrinsic affordances, whereas in the second case our interaction with it is shaped by the instructional affordances we identified.

4 Appropriating ICT for Instruction

The Oxford dictionary defines the verb appropriate as to "take (something) for one's own use, typically without the owner's permission." Bakhtin (1981) discussed appropriation in the context of language as the adaptation of words which are part of an external language and culture for personal use that reflects semantic and expressive intentions. Rogoff (1995) discussed appropriation in the context of participation in a community, and defined it as adapting the norms, behaviors, modes of participation in a community and becoming part of it.

Building on the work of Levrini, Fantini, Pecori, Tasquier, and Levin (2015) on students' appropriation of scientific ideas and epistemologies, Kapon (2015) operationalized the appropriation of a novel educational technology into a teacher's personal instructional repertoire composed of five complementary attributes of the uses of the tool. The first attribute is the way the tool is used as an expression of the teacher's personal instructional agenda. This attribute coheres strongly with Tabach's and Trgalová's (in this volume) emphasis on teachers' orientations as the third domain of mathematical knowledge for teaching with technology. Milner-Bolotin's (in this volume) appropriation (as a teacher educator) of CALS in her methods for teaching STEM courses, for example, reflects her pedagogical agenda to nurture the development of reflective practices in prospective teachers. Zazkis's (in this volume) appropriation (as a teacher educator) of many of the ICT tools she discusses in her chapter stems from the goal of educating future mathematics teachers to become more skeptical of technology-inferred inferences.

The second attribute is that the way the tool is used is grounded in the discipline that is being taught. This attribute was abundantly apparent in Zazkis's (in this volume) appropriation of technology in her teacher education classes, in particular, her use of calculators to investigate the decimal expansion of fractions to highlight the formal definition of rational numbers. Tabach's and Trgalová's (in this volume) call for disciplinary-specific standards (mathematics in their case) regarding the use of ICT also coincides with this attribute.

The third attribute is that the way the tool is used involves a metacognitive and epistemological dimension, in the sense that the teacher consciously knows why s/he chose the tool from a personal and disciplinary points of view. These explanations are found often for instance in Milner-Bolotin's writings on her appropriation of ICT tools for the instruction of prospective STEM teachers. They also cohere with Tabach's and Trgalová's (in this volume) emphasis on the importance of teachers' orientations.

The fourth attribute is that the way the tool is used is non-incidental, in the sense of being consistently used throughout instructional activities; and the fifth is that the tool's use entails social relationships that position the teacher within the classroom as well as within the broader educational community. These attributes emerge from all three chapters. Miner-Bolotin, for example, provides a concrete example of using the technology to position students as collaborating colleagues.

5 Teachers' Professional Knowledge

Zazkis (in this volume) describes a case in which she was surprised when her students confidently cited an incorrect mathematical definition from Wikipedia as the "commonly accepted definition". She and her colleagues later found out that it was taken from a Wikipedia discussion (and not a Wikipedia article), which is a forum, rather than a reference for conventionally accepted definitions. I interpret this as missing epistemic knowledge (i.e., understanding sourcing. See for example Bråten, Ferguson, Strømsø, & Anmarkrud, 2014), and not mathematical knowledge per se. In the same manner, one cannot treat all interactive mathematics applications with the same degree of confidence. There is a huge difference in the reliability of interactive mathematical applications available today. Some are professionally used and validated, whereas others (many of the online free mathematics applets) are not subjected to such validation processes. Understanding this point is a basic prerequisite for the productive use of the tool. The degree of skepticism employed should be correlated with this information.

All three chapters highlight the importance of teachers' knowledge in the productive implementation and uses of technology in education. Tabach and Trgalová (in this volume) propose a theoretical model of mathematical knowledge for teaching with technology that comprises three domains: (1) teachers' orientations, that encompasses teachers' beliefs and motivations; (2) teachers' knowledge, which is represented by an adaption of a model of pedagogical content knowledge (Ball, Thames, & Phelps, 2008) to which the use of technology is infused; and (3) teachers' double instrumental genesis as related to technology, which reflect the informed practice of using the technology.

I prefer to think of professional knowledge for teaching as a knowledge system that informs the teacher’s practice, rather than a set of static categories. Information about the world is not transparently available. Our knowledge system provides ways of perceiving the “right” and the "relevant" information (diSessa & Sherin, 1998; diSessa & Wagner, 2005; Kapon, Ron, Hershkowitz, & Dreyfus, 2015; Wagner, 2010). The teacher’s knowledge system informs the perception of instructional affordances, and the motivation and ability to appropriate instructional resources (what Tabach and Trgalová, in this volume, refer to as teacher orientation). The teacher’s knowledge system adapts as a result of feedback from students, peers, and hopefully also teacher educators (Kapon, 2015).

6 Implications for Teacher Education

The conceptualization of teachers’ knowledge informs how we design teacher education programs. If we agree with Tabach and Trgalová (in this volume) that supporting the development of personal instrumental genesis of ICT is an important aspect of teachers’ knowledge, and that most prospective teachers do not begin their training armed with this knowledge (in line with Zazkis’s and Milner-Bolotin’s claims), then prospective teachers should spend significant time during their training developing their personal instrumental genesis. The goal of this training should be to turn these teachers into proficient, natural users of the technology in question, and make this technology an integral part of their distributed cognition, thus enabling them to become proficient problem solvers with it. Note, however, that this is only the first step in their training since prospective teachers should also develop their professional instrumental genesis with regard to ICT. In particular, they should spend significant time experimenting with adapting ICT tools for the purpose of teaching something, testing these adaptations, and adjusting their adaptations accordingly. The problem is the huge number of available ICT tools, the constant updates in these tools, and their relative short lives. One possible solution might be to (1) engage preservice and in-service teachers in *scaffolded* self-learning of new technologies, and through this process highlight the epistemic features and awareness of the intrinsic and instructional affordances and constraints of the tool; (2) embed into the learning process structured “feedback loops” (Laurillard, 2012) that evaluate “live” appropriations of these instructional tools, in which prospective teachers try out their instructional appropriations, and engage in iterative loops of reflection and redesign (Kapon, 2015).

Milner-Bolotin (in this volume) asks “how we can break the apparent paradox of having unprecedented access to educational technologies and yet making little progress in student STEM learning?” In my view, this is not necessarily a paradox. More technology does not inherently imply better learning; it merely implies different forms of learning. As Miner-Bolotin (in this volume), Zazkis (in this volume), and Tabach and Trgalová (in this volume) argued, the growing presence of ICT tools in our educational system is inevitable. The important message should be that ICT tools can provide different patterns and forms of instruction and learning, which are not inherently good or bad. It is how (and if) they are appropriated for teaching and learning that determines their educational value. Hence, progress in STEM learning is not a function of technology itself, but rather a function of the use STEM teachers and learners make of it. Indeed, the era of educational technologies presents a myriad of emergent STEM teaching possibilities for teachers, and teachers should be constantly empowered to enhance their pivotal role in students' learning.

References

Bakhtin, M. (1981). Discourse in the novel. In M. Holquist (Ed.), *The dialogic imagination* (pp. 259–422). Austin, TX: University of Texas Press.

Ball, D. L., Thames, M. H., & Phelps, G. (2008). Content knowledge for teaching what makes it special? *Journal of Teacher Education, 59*(5), 389–407.

Bråten, I., Ferguson, L. E., Strømsø, H. I., & Anmarkrud, Ø. (2014). Students working with multiple conflicting documents on a scientific issue: Relations between epistemic cognition while reading and sourcing and argumentation in essays. *British Journal of Educational Psychology, 84*(1), 58–85. https://doi.org/10.1111/bjep.12005

diSessa, A. A., & Sherin, B. L. (1998). What changes in conceptual change? *International Journal of Science Education, 20*(10), 1155–1191.

diSessa, A. A., & Wagner, J. F. (2005). What coordination has to say about transfer. In J. Mestre (Ed.), *Transfer of learning from a modern multi-disciplinary perspective* (pp. 121–154). Greenwich, CT: Information Age Publishing.

Gibson, J. J. (1986). *The ecological approach to visual perceptions*. Boston, MA: Houghton Mifflin.

Greeno, J. G. (1994). Gibson's affordances. *Psychological Review, 101*(2), 336–342.

Haspekian, M. (2011). *The co-construction of a mathematical and a didactical instrument*. In M. Pytlak, T. Rowland, & E. Swoboda (Eds.), Proceedings of the 7th Congress of the European Society for Research in Mathematics Education (CERME7) (pp. 2298–2307). Rzeszów.

Hutchins, E. (1995). How a cockpit remembers its speed Hutchins. *Cognitive Science, 19*, 265–288.

Hutchins, E. (2006). The distributed cognition perspective on human interaction. In N. J. Enfield & S. C. Levinson (Eds.), *Roots of human sociality: Culture, cognition and interaction* (pp. 375–398). Oxford, UK: Berg Publishers.

Kapon, S. (2015). From new educational technologies to a personal-instructional repertoire. In M. Grangeat (Ed.), *Understanding science teachers' professional knowledge growth* (pp. 171–185). Rotterdam, The Netherlands: Sense Publishers.

Kapon, S., Ron, G., Hershkowitz, R., & Dreyfus, T. (2015). Perceiving permutations as distinct outcomes: The accommodation of a complex knowledge system. *Educational Studies in Mathematics, 88*(1), 43–64. https://doi.org/10.1007/s10649-014-9570-2

Levrini, O., Fantini, P., Pecori, B., Tasquier, G., & Levin, M. (2015). Defining and operationalizing 'appropriation' for science learning. *Journal of the Learning Sciences, 24*(1), 93–136.

Laurillard, D. (2012). *Teaching as a design science: Building pedagogical patterns for learning and technology*. New York, NY: Routlage.

Milner-Bolotin, M. (in this volume). Deliberate pedagogical thinking with technology in STEM teacher education. In Y. B. D. Kolikant, D. Martinovic, & M. Milner-Bolotin (Eds.), *STEM teachers and teaching in the digital era*. Cham, Switzerland: Springer.

Rabardel, P. (2002). *People and technology – A cognitive approach to contemporary instruments*. Retrieved from https://hal-univ-paris8.archives-ouvertes.fr/file/index/docid/1020705/filename/people_and_technology.pdf

Rogoff, B. (1995). Observing sociocultural activities on three planes: Participatory appropriation, guided appropriation and apprenticeship. In J. V. Wertsch, P. del Rio, & P. Alvarez (Eds.), *Sociocultural studies of the mind* (pp. 139–164). Cambridge, UK: Cambridge University Press.

Stevens, R., & Hall, R. (1998). Disciplined perception: Learning to see in technoscience. In M. Lampert & M. L. Blunk (Eds.), *Talking mathematics in school: Studies of teaching and learning* (pp. 107–149). New York, NY: Cambridge University Press.

Tabach, M., & Trgalová, J. (in this volume). Teaching mathematics in the digital era: Standards and beyond. In Y. B. D. Kolikant, D. Martinovic, & M. Milner-Bolotin (Eds.), *STEM teachers and teaching in the digital era*. Cham, Switzerland: Springer.

Wagner, J. F. (2010). A transfer-in-pieces consideration of the perception of structure in the transfer of learning. *The Journal of the Learning Sciences, 19*(4), 443–479.

Zazkis, R. (in this volume). Technology in mathematics teacher education: On trust and pitfalls. In Y. B. D. Kolikant, D. Martinovic, & M. Milner-Bolotin (Eds.), *STEM teachers and teaching in the digital era*. Cham, Switzerland: Springer.

Shulamit Kapon is an assistant professor at the Faculty of Education in Science and Technology at the Technion – Israel Institute of Technology. Shulamit is interested in the interrelations between teaching and learning, with a focus on explanations and sensemaking, the nature and appropriation of scientific and epistemic practices and professional habits of mind. She examines these issues in the context of research apprenticeships, authentic classrooms, and physic teacher education. An important goal of her work is to use this knowledge to improve STEM and particularly physics education in Israel and beyond. She was trained as a physicist at the Technion (B.A. and M.Sc.), as a science education researcher at the Weizmann Institute of Science (Ph.D.), and as a learning scientist at the University of California Berkeley (Postdoc), and was a high school physics teacher for twelve years. At the Technion she leads the Physics Teachers Education program.

Part V

Teachers' Knowledge for Successful Twenty-First Century Teaching

Issues of Teaching in a New Technology-Rich Environment: Investigating the Case of New Brunswick (Canada) School Makerspaces

Viktor Freiman

1 Introduction

Makerspaces are known as learning spaces (digital fabrication labs, or 'fabulous labs', introduced in early 2000s in the United States; Gershenfeld, 2012). They present different layouts, in which students engage in a multitude of projects, during which they explore various technologies, create new things of all kinds, and share their results with others (Brilliant Labs, 2017). Thus, these labs provide an environment in which students can design, experiment, build and invent while learning about STEAM ('A' is often added to STEM to express a close connection of makerspaces to the Arts). Activities can range from cardboard construction to electronics, programming, robotics, and sewing. These informal activities, although previously known, took a new life in the early 2000s with the advent of Information and Communication Technology (ICT).

According to Oliver (2016), makerspaces take many forms but generally involve a physical (often non-classroom, e.g., in public libraries) space with shared resources to pursue technical projects of personal interest with the support of a maker community. Thus, "making is more commonly practiced in after-school camps and clubs, making has the ability to enrich the school-day curriculum and bridge formal and informal learning contexts" (Oliver, 2016, p. 160). In a K-12 context, according to Niederhauser and Schrum (2016), there is a "relationship between the maker movement and the effort to increase STEM-related curriculum and interest in STEM careers and to move beyond current career" (p. 329). According to Peppler and Bender (2013), the latter helps students to "make their own jobs and industries" (as cited in Niederhauser & Schrum, 2016, p. 329).

V. Freiman (✉)
Université de Moncton, Moncton, NB, Canada
e-mail: viktor.freiman@umoncton.ca

Y. Ben-David Kolikant et al. (eds.), *STEM Teachers and Teaching in the Digital Era*, https://doi.org/10.1007/978-3-030-29396-3_15

Besides establishing and promoting learning in a variety of technology-rich environments, Hagel, Brown, and Kulasooriya (2014) emphasize the involvement of "different players acting in the maker ecosystem – beginners, collaborators, and market innovators" (as cited in Oliver, 2016, p. 160) in the maker movement. Referring to Maker Media (2013), Oliver (2016) also argues that makerspaces can be implemented across K-12 grade levels, to include easier electronic circuit projects and programming languages like Scratch for the elementary grades and more challenging 3D modeling and programming languages like Arduino for middle and high schools. In this (nearly informal) context (disregarding the concrete location of the makerspace), learning is seen as both an autonomous activity (self-directed learning, problem-solving) and a networking activity (self-determined learning, problem posing, and collaboration with others to build together a path of investigation).

Makerspaces are a relatively new phenomenon in the K-12 education system, which has gained ground during the past decade in many countries, including Canada (Sheridan et al., 2014; Hughes, 2017). In New Brunswick, first school makerspaces were established in 2014–2015, initiated and piloted by Brilliant Labs, a non-profit group that "supports integration of creativity, innovation, coding, and an entrepreneurial spirit within classrooms and educational curricula" (Brilliant Labs, 2017) across Atlantic Canada. While the status of makerspaces is not officially established by the provincial authorities yet, the initiative, at its pilot stage, mainly relies on enthusiastic teachers, usually supported by school administration, and is grounded in strong connections between the schools and the community. Yet, from the teachers' perspective, it remains unclear what does "to fully embrace makerspaces" (Adcock, 2018) actually mean. There are some other important questions: *How to integrate making-activities into one's teaching? What are the connections to the curriculum? How does this environment impact teaching and learning across subjects? What are the issues the teachers deal with?* These are the main issues that will be addressed in this chapter.

In the maker pedagogy, the teacher is first and foremost a guide or a facilitator, with the main focus being to accompany students in a culture of collaboration and curiosity (Gerstein, 2016), a role which has been envisioned in numerous NB ICT-related initiatives since 2000, but until recently, neither fully understood nor implemented in everyday practice. Our study aims to clarify the elements of this pedagogy that emerge from activities in school makerspaces, as well as different issues and (system-wide) challenges related to teaching in these new environments.

The study of makerspaces could be significant in terms of both the usage of digital tools and development of twenty-first century skills. These are achieved through multiple interdisciplinary and transdisciplinary connections (e.g., collaborative problem-solving, encouraging creativity and innovation). Also, new teaching methods and strategies are being employed in this innovative and rather informal learning context for the K-12 formal school system. Keeping this in mind, our first set of data, which was collected at the end of the 2015–2016 school year by means of on-site observations of six makerspaces (including video-recording, students' survey, and interviews with teachers and students), was used to draw a detailed portrait of this innovative school practice. The selection of schools was made based on suggestions of our partners (Brilliant Labs) who were working with schools in establishing and equipping makerspaces, as well as accompanying students and teachers in a variety of making activities by providing on-site training and support.

We shall start by briefly describing the context of NB, its school system and various initiatives of integrating ICT in teaching and learning since 2000 up to the recent introduction of makerspaces.

2 Brief Overview of NB Educational Reforms in the Early 2000s: 'STEMing' Schools Up

Having a quite unique educational system, as an officially bilingual (French and English) province, New Brunswick strives to enable K-12 schools to better respond to the social and economic challenges of the twenty-first century, both locally and globally (Chiasson & Freiman, 2017). Several important steps have been undertaken since 1990: A Commission led by Landry and Downes on Excellence in Education was established to generate a debate about how to better prepare students for the twenty-first century. In May of 1992, a report on excellence in education entitled, *Schools for a New Century*, was released setting up a stage for a profound school reform (GNB, 1992). One of the main ideas of the report was to change the perspective from being locally- and provincially-oriented, in order to align the education system with global trends:

> Back in the 1960's we needed to change the standards of education from a local to a provincial perspective. Today, our standards must match up nationally and internationally, so that our students can compete with the best in the world. (Govt. of New Brunswick, 2000)

In order to reach this goal, in 2000, New Brunswick Government has begun a complete revision of the school curricula. Each subject-based curriculum, on the French side, is now based on the Common K-12 Framework (MEDPE, 2016), which establishes six transdisciplinary learning outcomes: appreciation of cultural identity and heritage, personal and social development, ability to communicate, organizational skills, critical thinking and creativity, as well as ICT competencies. It also includes 13 guiding pedagogical principles, among them interdisciplinarity and transdisciplinarity, to emphasize the ability to transfer knowledge, skills, and attitudes.

Moreover, in response to a so-called 'PISA-shock' addressing the fact the province scored below other Canadian provinces in the first international comparative PISA study in 2000 (Freiman & Lirette-Pitre, 2007), the province has adopted a *Quality Education Agenda,* which included a pilot study exploring the use of One-to-One laptop (one laptop per student) in a hope of improving students' results in mathematics, reading, and science. Despite positive reports from both French (Blain et al., 2007) and English sectors (Milton, 2008), the government abolished the initiative in 2007, and changed its Strategic Plan overall. From 2007 to 2013, the focus of the reform was put on teacher-initiated innovations, which addressed, as priority areas, literacy, numeracy, school inclusion, and use of technology (Government of New Brunswick, 2008).

This initiative included, among others, the Innovative Learning Funds to support teachers' ideas to make learning more meaningful by experimenting with novel approaches to teaching, such as a robotics-based learning we studied in 2008–2010 (Blanchard, Freiman, & Lirette-Pitre, 2010; Savard & Freiman, 2016).

A new 10-Year Provincial Education Plan (GNB, 2016) sets new objectives for both linguistic communities, which are (although not being identical for both sectors) clearly oriented on competencies-based, inter- and intra-disciplinary career-oriented learning. While STEM is explicitly mentioned only in the French version of the Plan, a focus on mathematics (numeracy), science, and technology is clearly identifiable in both versions.

While in-depth analysis of successes and challenges of these initiatives are beyond the scope of the chapter, it is quite safe to suggest that technology (or, more precisely, digital technology) has been identified by the province one of important components of change in the provincial education system over the past two decades leading to the emergence of several innovative teaching practices. As the work on realisation of the ideas of STEM education is at its first steps, many technology-based innovations can be viewed as precursors of today's shift of the focus on STEM disciplines, and, as one of its possible forms, on establishing school makerspaces.

3 Makerspaces as a New Form of Teaching and Learning

Elements of maker pedagogy can be retraced in history. Indeed, the works of Dewey (1916), Piaget (1956), Vygotsky (1978), Papert (1980), and Lave and Wenger (1991) have influenced the STEAM movement (Litts, 2015). Martin (2015) cites Montessori's (1912) ideas of bringing children to learn by building with interesting tools and materials. The tools have evolved, but the big idea is the same. In fact, Niederhauser and Schrum (2016) consider "making" as a pedagogical orientation with its main focus on "integrating creativity and imagination with design and encourages problem-finding in addition to problem-solving" (p. 359).

Several possible learning benefits of this pedagogy are mentioned in the literature. Interdisciplinarity is often found to be one of the main advantages of school makerspaces that have a particular focus on STEAM skills (Litts, 2015). Sheridan et al. (2014) argue that the work in makerspaces fosters students' autonomy and collaboration. Other elements mentioned in the literature are the development of critical thinking and argumentative skills (Litts, 2015), the increase in the capacity to do problem-solving, as well as the use of gaming in learning (Vongkulluksn et al, 2018), which can make learning more cooperative (Wardlow and Harm, 2015).

Overall, the researchers seem to agree that when working on their projects, students explore different possibilities for their future career choices (Litts, 2015), while becoming active members of their learning community (Sheridan et al., 2014). Moreover, this experience seems to engage and motivate young learners because they do work according to their personal interests (Litts, 2015). Some researchers have also observed increased perseverance and self-esteem among the learners (Blikstein, 2013).

In relation to new sets of (digital) skills needed for young people to successfully build their career paths in the Canadian workforce, Martinovic and Freiman (2013), based on a systematic literature review, have identified several factors that affect a student's decision to use technology for learning. Among them, (a) educational compatibility (of digital affordances with personal learning styles), (b) conditions that facilitate learning (i.e., the support provided to the students via lifelong, learner-centered, and self-directed pedagogies), and (c) encouragement from teachers for technology use (p. 2). Many of these factors can also be considered as key aspects of pedagogy that teachers use in the makerspaces.

However, from the teachers' (or more broadly, educators') perspective, realizing the educational potential of makerspaces based on these aspects is not without a danger, according to Gilbert (2017), who insists on the importance of focusing when bringing maker culture into the school system. In other words, the key issue, according to the author, is about the meaning of 'productivity'. Namely, while people working in makerspaces are producing a lot of physical objects, the real educational value, in terms of productivity, consists in producing ideas: "expressing them, playing with them, testing them, trying them out in different combinations" (Gilbert, 2017, p. 94). In the next sections I will keep this theoretical focus in mind when analyzing how school makerspaces we visited were organized and how they impacted teaching and learning, especially in terms of teacher-innovator's practice.

4 Analyzing the First-Year Data

Since 2016, a team of researchers from the Université de Moncton involved in the partnership development of network CompeTI.CA (ICT competencies in Atlantic Canada) has been following makerspaces movement in NB schools from a variety of angles: digital literacy skills development, STEM education, and twenty-first century skills (Freiman et al., 2016, 2017; Djambong, Freiman, Gauvin, Paquet, & Chiasson, 2018; Léger & Freiman, 2018). In this section, I focus on teachers and teaching.

During the first year of the study, the CompeTI.CA research team has decided to focus on three French and three English schools located in different parts of the province (North-East – one French and one English school, North-West – French school, Center – English school, South – English school, and South-East – French school), among them three elementary (Grades K-8) schools, two middle schools (Grades 6–8), and one high school (Grades 9–12). Three schools had well established makerspaces, two schools were at the mid-way point of setting up and one school had it just started. Overall, nearly 150 students were participating in the study, along with 15 teachers, one school principal, and four community members (two volunteers, one community college teacher, and one member of *Brilliant Labs*).

From our first year of study, we have learned about remarkable diversity in how the teaching and learning in makerspaces were organized and functioned in each of the six participating schools. At the same time, based on video observations and semi-structured interviews with school administrators, community experts, teachers, and students, we were able to identify several patterns of teachers' involvement, their work with students, as well as their overall role in the makerspace's activities. We shall first describe some special features of each school, then how the teachers perceived their involvement in the makerspaces and students' participation.

On a school level, we can safely conclude that all participating schools (and teachers) seem to have had a sound record of innovational practices integrating (digital) technology which has created a basis of establishing and developing makerspaces. For instance, one of the schools (**first case**) started its innovative projects in the early 2000s being involved in one-to-one laptop study, then continued with interdisciplinary project-based learning, robotics-based learning, and finally started makerspace in 2014. Being located in a small village and enrolling students from several other villages, this K-8 school has a unique vision of the twenty-first century learning: strong pedagogical leadership and enthusiastic teachers, significant help from the local community, and openness to the world (e.g., every student and every teacher has an individual blog; every student's project is made public; school conferences with internationally and nationally renowned experts featuring new ways of teaching and learning; large network of collaboration supported by social media like Twitter). Students are also contributing to the school 'Wikipedia' featuring francophone Acadian culture and identity. Located near the school library, the makerspace occupies two classrooms with a wall between them being removed (this space was previously used for robotics-based activities). Along with tablets and robotics kits, a lot of different technologies are available (*Minecraft*, Virtual Reality, 3-D printers, among others).

In order to start their projects, students from Grades 4–8 who wanted to work on a project had to fill in an online form with the proposal explaining the goals and anticipated results. They could choose to work in groups or individually. Since the projects were not explicitly related to the curriculum, students could work on them during some special periods devoted to selected topics (like sport-arts-study); some of them used to come voluntarily to pursue their work during the lunch hours. Some teachers could use makerspaces for projects related to the science curriculum.

One teacher (also acting as a school principal) had a part of her workload devoted to supervising students' work and helping them to choose a project, and to learn how to use project-related technologies (without giving a detailed explanation but rather directing to different sources of information – such as online tutorials). The teachers who used or supervised activities in the makerspace did not necessarily have a technical degree but were convinced that having students work in the makerspace corresponds to their vision of how the learning should look like in twenty-first century school, and how they could stimulate students' explorations with different technologies teachers themselves were not familiar with. The school administration constantly works on updating materials available to students by providing them with new technological tools. Teachers also get help from *Brilliant Labs* staff, who occasionally visit the school, make presentations and conduct workshops with students, along with helping them to work on their projects. A clear success of the makerspace for students from Grades 4–8 has inspired K-3 teachers to push forward the establishing their own lab for youngest makers.

The **second case** is a Grades 6–8 middle school located in the urban area (provincial Capital region). A technology teacher who was in charge of the makerspace at the time of the first research visit also had a record of being one of the innovative teachers whose projects were funded by the *Innovative Learning Agenda Program* in 2008. Her engagement in makerspaces was supported, on one side, by the school administration as well as by the *Brilliant Lab* staff who contributed the equipment and expertise in students' projects. Some of the local IT companies have also provided help with the equipment. We could see that many projects realized by students in the makerspace were connected to mathematics curriculum (supported and encouraged by the mathematics teacher) and to music education. Along with designing their own projects (which they often did during the mathematics class after finishing their regular assignments), the students were also encouraged to re-invest programming skills they gained during broad-based technology classes (i.e., using *Scratch* environment), to create their own projects in the makerspace. The makerspace was also equipped with the 3-D printer and *Arduino* Kits, along with other tools for making.

The **third school** is a K-8 elementary school located in a small rural area in the south-eastern part of the province. The school makerspace has been established by combined efforts of two innovative elementary teachers supported by a strong school leadership, as well as a non-profit organisation, *Place aux competences* (More Room to Competences),[1] which has contributed funds for a makerspace mentor. One of the teachers is well known in the province for her innovative use of ICT in teaching young children, along with development of entrepreneurial culture in her students. Some of the projects she undertook were: creating and producing books by Grade 1 students and *Twitterature* project with Grade 7 students. She also integrates Minecraft and Scratch technologies into her teaching using desktop computers in her classroom. The second teacher was one of the initiators of innovative learning space she used to motivate students' school work through the project-based learning approach in all Grade 4–5 subjects. At the time of our visits, several students were working on their own ideas in the makerspace (which occupied one otherwise empty classroom).

Most of the projects we could observe were done by small groups of two to three students. Makerspace was equipped in a similar way as in the first two schools described above: there was a 3-D printer, *Arduino*-kits, *LEGO*-robotics kits, and a powerful desktop computer with the design software. The work of students on their

---

[1] This organization work with K-12 schools to promote competencies-based learning which is also oriented on career building and entrepreneurship.

projects in the makerspace was also supported by one of the *Place aux competences* stuff members who does not necessarily have a teaching degree yet works enthusiastically with students from several regional schools to help them in the realization of their projects. Besides working on their projects, students also started giving lessons in programming and robotics to their younger peers from Grades K-3.

The **fourth school** is a middle school (Grades 6–8) located in a small town in the southern part of the province. A space which featured philosophy of making exists in this school since 2001 within a multimedia lab equipped with *Apple* computers and publishing multimedia software, which enables students to produce a high-quality publishing material (such as booklets and school yearbooks), as well as school videos. The facility also has an integrated kitchen, which was used by students not only to learn cooking but also to make their own food (e.g., pizzas) and fund other projects by selling it to the community. The lab is run by a technology teacher who also has an engineering degree (before making teacher certificate). He organizes teaching in a hands-on manner, so students get a chance in developing practical life skills that would shape their interests in different technologies along with providing students with entrepreneurship experience of doing real projects, thus preparing them for future career choices.

By emphasizing collaboration as key competence, the teacher involves students not only in a teamwork with their classmates but also gives them roles of mentors, once they are in Grade 8 so they could coach their younger peers by sharing their expertise and helping them in learning about new technologies. Besides the media lab, the school also integrates technology in arts teaching (numerous projects are done in the classroom specifically assigned for arts and crafts classes), and, in the year we visited it, they were starting a makerspace (using another room) as a place for sparking creativity in students involved in robotics and computer programming activities.

The **fifth school** (K-8) is situated in a small town in the north-eastern part of the province. It has a status of a community school (école communautaire), a concept promoted in 2007–2008 by the provincial education plan *Kids Come First* (which also created the mentioned above *Innovation Learning Agenda Funds* for teachers). This concept, while targeting constant innovation in teaching and learning, was explicitly anchored in the development of students' interests and talents closely connected to the regional and provincial socio-economic values and needs for sustainable development. The community schools promote, among others, enriched learning, positive school environment, support to families, and citizenship, while giving students a role of initiator, implementer, and project manager (Levesque, 2011).

This is where the goals of makerspaces and community schools were joined resulting in establishing the school's makerspace. Hence, the parents' committee, the community school representative, local businesses, school leaders, and teachers have chosen to equip a former school library space with a 3-D printer, LEGO robot kits, electric circuits building kits, crafts and arts material, among else, to let students choose and realize a number of projects within a short period of time. The project began in January 2016 and we visited the school in June 2016 when students presented first projects to their parents during the open school day. The work in the makerspace was supervised by two parents, one with a strong background in computer science and the other as a certified elementary teacher working part-time as a supplementary teacher. Both were working as volunteers by guiding students through their making activities.

The **sixth school** is a High School (9–12) situated in an urban area in the northeast of the province. Back to 2014, two teachers, a technology teacher (specialist in computer science who became certified teacher) and environmental sciences and mathematics teacher who had been already involved in innovative projects (for example, live video streaming showing the progression of the fish development in all schools), decided to apply for funding with *Brilliant Labs* and to work collaboratively on establishing a makerspace.

One of the teachers succeeded to get approval for including learning in makerspaces into a formal curriculum as an entrepreneurship Cooperative Education course (COOP). According to the curriculum guidelines, this course integrates "classroom learning with actual workplace experiences" by placing students "at worksites where they are provided with challenging responsibilities and learn by doing. In this way, learning and experience are combined in an educationally beneficial way" (NBDE, 2006).

As mentioned in the course outline, the students explore STEAM projects that involve Science, Technology, Engineering, Arts, and Mathematics, and which are "creative, innovative and entrepreneurial." Students were expected to design and to engineer their own projects by exploring a variety of technologies. Once their design is completed, students work with mentors from the community in order to turn their projects into "entrepreneurial ventures." Being explicitly oriented towards a workforce, students could closely collaborate with the local Community College and businesses. The course is built upon the "4 C's…Creativity, Critical Thinking & Problem Solving, Collaboration, and Communication" (Love, 2015) model to provide students with skills beneficial in any workplace and essential for life-long learning.

5 Characteristics of Successful Innovative Teachers in the Context of Makerspaces

While each school has its own way to organize the makerspace and students' work, our data reveal some common characteristics about teachers and their view of learning.

The **first common characteristics** is that all teachers who participated in our study, who either ran a makerspace or used it for their teaching, have had a sound history of integrating in their practice a variety of pedagogical innovations in technology-rich environments, such as using students' blogs or other media, online problem solving, teaching in one-to-one classroom, and using programming software (such as Scratch) with their students, in addition to project-based and inquiry-based learning activities.

While getting a taste of technology-enhanced teaching, these teachers felt a need for change when the opportunity of having a makerspace arose. One teacher (T1) who worked first as a computer technician setting up networks in schools, before becoming a certified technology teacher, said how he started to get a feeling of losing the ground:

> I have that [technology] background, but the big thing I find out after 11 years in, I'm losing a lot. I find I'm losing some of my skills…that's the thing—you have to be self-motivated and it's kind of overwhelming sometimes, especially if you have different levels [of students' abilities]. (T1, interview data)

Another teacher (T2) who teaches technology to Grades 6–8 students tries to implement his vision of progressive learning over the years while doing similar types of projects. First, Grade 6 students get introduced to different types of technologies to become familiar with their affordances at some basic level; then, in Grade 7, they deepen their knowledge and sharpen their skills, whereas, coming to Grade 8, they become mentors for newcomers (from Grade 6), so acquiring important leadership skills; also, at this level, students start creating their own products, like apps, so eventually contributing to the community. Overall, observing the outcome of such an approach, the teacher said:

> Working with technologies, doing real [life-related] stuff, students can gradually develop sets of skills that make them employable in the future when they leave the school. (T2, interview data)

As a result of their experience, teachers have not only acquired some expertise on integrating technology and trying out new pedagogies, but they would also have developed that what Couros (2015) calls 'innovator's mindset' to empower learning, unleash talent and foster culture of creativity. As a teaching philosophy, the innovative mindset combines (1) a *clear vision* of new opportunities for twenty-first century learners, (2) a *know-how* related to implementation of this vision, along with (3) a *deep understanding* of this way of teaching not as an add-on to the 'traditional classroom', but as an essential type of learning for their students. With no surprise, we noticed these elements in makerspaces teachers' discourse and actions.

The **second characteristics** is that without having similar education and background in relation to either pedagogy or technology, these teachers have developed a genuine sense of resilience while dealing with a variety of issues – from how technology works and why it sometimes does not, to aligning their pedagogical approach with the official curriculum, often taking a certain amount of risk of going beyond the prescribed content. They also knew how to get help from outsourcing (using online resources along with their professional networks, and beyond). They were all getting a strong support from school leaders, who support teachers' initiatives and provide necessary financial and pedagogical help especially when it comes to equipping the school with technology.

For example, one teacher said (T3):

> *Here, in this school, we are fortunate to have a strong WI-FI network, so that every student can bring his own device and get an Internet connection in any class when he needs this. The school also has a technology lab … there has been a kind of makerspace here in school for 15 years.* (T3, interview data)

Having this support, the interviewed teachers said they tend to extend their circle of support by involving parents, community, university, business, and government. For example, the school that runs a mentioned above COOP course counts on help from the local community college. The other school has an employee from the *Place des Competence*, a non-profit organization coming to work with students and teachers in the makerspace. One teacher (T4) said, "I'm here so I can guide people – would it be teachers or youths – and I help them to develop things in the makerspace" (T4, interview data).

With the overall positive view of makerspaces as the environment that provides students with authentic and engaging learning opportunities that fit into the vision of the twenty-first century school, some issues remain open. For instance, the question of how informal the organization of students' work should be. One volunteering parent (who is also a certified teacher; T5) reflected on this issue:

> [*… when you set up the system requiring student to*]*take a project, you must submit a project, you have to keep working on your project, on that side we have a few students [whose] frequency of visits to the lab has decreased because they liked to come here as if they were learning centers and you could ... kind of like in kindergarten ... you can change center every day and then um ... go from one side to the other so uh ... we lost a bit of that flexibility by ... putting ... the idea of submitting a project, working on it and not changing projects until you're done so uh ... is this good? Is this bad? Is there a room for both? You have to wonder … is this okay when someone comes [here] and he just learns little bits, little pieces, so he tasted a little of everything, or do we really want him to invest in long-term projects?* (T5, interview data)

Another issue mentioned by the same participant (T5) is related to the complexity of the organization of the students' work in the makerspace, in respect, among others, to the regular school routine:

> *... with regard to [teacher's] practices, well, it requires from the teacher to arrange the schedule so that the group can come to the creative lab, if the teacher wants to do it during his school hours; then it requires from the teacher... to decide, since it is not in the program, there is no New Brunswick Ministry program "Creative Lab", so the teacher must make sure that he doesn't penalize an education program [curriculum], you know, the teacher must always remain aware of it. And, like the class that came here today, is there a de facto return to what was done, and an assessment of the student's work with regard to the learning, while linking it to the curriculum?* (T5, interview data)

The **third characteristics** is that these teachers develop a particular way of teaching by establishing a supportive, encouraging, caring, and risk-free learning environment for all students. Their approach is essentially inclusive, while targeting each student's higher potential. One teacher (T6) explained the opportunity to do so in the context of makerspace class:

> *it's a room in which some of the kids who go underneath the radar [in the traditional classroom] can actually possibly have an opportunity to really show some of their talents here; this experience constitutes the whole transformation of teaching from being one that's concept driven and curriculum driven [so, I needed to get out of that] … I saw this opportunity with projects and I wanted something that students would maybe find a little more passion in as opposed to going around checking math homework which 75% of them haven't done.* (T6, interview data)

Teachers knew well their students, their identities, their learning styles, their personalities, and their needs, thus being able to lead their students forward through that what is called by Quinton and Smallbone (2010) as a 'feeding forward' model.

A lot of value in the makerspace is being put on students' collaborative work making students not only work together but also help each other based on everyone's unique forces, according to one teacher (T4):

> You do not see [students' failures] here, with a new way we work today with technology. To help each other, because I told them it is impossible for one person to be an expert in all technologies, this changes too fast, it is impossible. So, students will learn to help each other while working together, sometimes 2-3 students on the same construction [in Minecraft]; they need to cooperate even working on different computers but doing the same project [designing a building]. (T4, interview data)

Another teacher's comment (T4) explains how affordances of makerspace environment and different tools help her students to create, to get a feeling they can progress by trial and error; where the error does not lead to the failure but rather prompts to pursue their work:

> *[Students] use tools that will get them to surpass themselves, so [for example] Minecraft helps to create, Ok! But if you go to Scratch, it's another way of thinking, you have to come back, tell your character in so many seconds, I want you to be there. Well, it's trial and error. Already there is a lot in trial and error [back and forth], so students are not afraid to make mistakes. The ways we worked in the past with our subjects, science for example, if you made a mistake and well it's the end of the world. The student says "I did not succeed", but with these tools [like Minecraft or Scratch], they do not experience failures.* (4, interview data)

Whether students are working alone or in small groups, progressing well or trying to fix a problem, a teacher is in constant movement watching students' work, asking questions, making comments, organizing discussions, so constantly interacting with them. This interaction does not mean that the teachers are experts in every project their students are trying to accomplish. Unlike many textbooks that would guide the learner through the solution of a problem through a number of steps, teachers in makerspaces leave students much room to try to solve problems by themselves, with minimum guidance. One teacher (T4) said:

> *I'm not being an expert, I'm not telling them how to do stuff, I'm not basically doing what a lot of textbooks do: here's your step one, here's step two, here's step 3. That's out the door because it's just not possible to do that with 10 or 12 different high-end projects on the go, right?* (T4, interview data)

Teachers could spend a few minutes with the whole class or a half an hour with one of the students. A lot of teachers' actions were 'on the spot', doing short-term management and making momentary decisions. Students seemed to appreciate the teacher's help when needed. One student (S1) said in the interview that his teacher is a 'role-model' who helps in the makerspace: "In the makerspace, well it is Mrs. M. [the teacher] because when I do not understand, well, I will ask her and she helps me."

Very rarely we saw teachers explicitly telling the students what to do and how to do it. They also accepted the fact that students were leaving the projects unfinished or abandoned work while valuing students' efforts and encouraged them to persevere in case students were hopping in and out trying to make a choice between different projects.

Regarding the assessment practices, our **fourth characteristics** is that except for one school having makerspace projects as part of the curriculum (a COOP course at the high school level), the final assessment was done informally by means of showcasing and sharing with peers, parents, and local community members, and for some projects at the regional, provincial, or even national and international level (this was used by a Co-Op-course teacher as well, but as an integral part of the formal assessment). Also, during the process of work on the projects and at the end of students' work, many of our teachers were showcasing students' accomplishments by means of social media (blogs, school websites, wikis, Twitter, and YouTube), sometimes accompanying them by comments expressing praise and delight.

For example, in the interviews, both one school principal and one community-school agent mentioned informal character of the assessment which takes form of 'pedagogical celebration' (for instance, the day we were in school there was an 'open house day' for parents who came to see projects their children were doing in the makerspace). This practice of assessment by means of showcasing was reported to be frequently used in the survey of assessment methods in makerspaces conducted by Peppler, Keune, Xia, and Chang (2014).

According to the school principal, school Facebook is used to value students' work. Also, in this school, some teachers were using certificates given to the students as recognition of their work in the makerspace. Hence, the students who have done a remarkable work were acknowledged during the gala.

6 Preliminary Conclusions and Points for Future Research

The maker movement was originated in often socio-economically disadvantaged communities, helping their members to realize creative ideas and to innovate with different types of technologies while trying to solve real-life problems. Some authors related this movement to a hope for "new, more prosperous economy," which is based on "personal fabrication rather than blind consumerism" (Peppler & Bender, 2013, p. 23).

Being originally 'non-school' or 'out-of-school' movement, makerspaces are gaining ground in school settings, sometimes as over-the-lunch, or after-school activities (Idem.). However, their integration into the formal curriculum in respect to learning outcomes and teaching practices remains unclear. This chapter has investigated these issues from the teachers' perspective, based on a project conducted across six school makerspaces in NB, Canada.

Since the beginning of the twenty-first century, NB provincial school system has been undergoing profound changes trying to incorporate in schools new learning spaces, which are technologically rich, project- and problem-oriented, inter- and transdisciplinary-minded, focused on valuing "rapidly changing and highly elastic set of transferable twenty-first century skills" (Galway & Gill, 2018). These skills include problem finding and problem posing, critical thinking, collaboration, and sharing of ideas. Makerspaces is one the latest innovative initiatives within this STEM-oriented trends in K-12 education (Ravipati, 2017) which is now on its raise in the province, as is the case in other Canadian provinces.

A case study presented here was conducted since 2016 by the CompeTI.CA team in collaboration with Brilliant Labs, an Atlantic-wide non-profit organisation which helps the schools to establish and run makerspaces. Our aim was to monitor teaching and learning in this new educational context. This chapter outlined some first-year data about how the makerspaces were **organized** and how teachers perceived **learning opportunities** for students to explore different cutting-edge technologies.

The six schools we visited in the first year represent diversity of provincial socio-economic landscape, two schools located in rural areas, two in small townships by the sea-side, and two in urban areas. Three of these schools are Anglophone and three Francophone, thus achieving linguistic variety in our sample. There was also a variety of types of schools and school levels. Hence, we had three schools with students at primary and middle school levels (Grades K-8), two middle schools (Grades 6–8), and one high school (Grades 9–12).

Except of one high school where makerspace was used in teaching a specific career-oriented course, thus following a more formal curriculum, other schools were integrating makerspace activities in some informal way during the school day; this could be particular days and hours devoted to activities in makerspaces (for students who were engaged in projects of their choice), or in some schools students could come and work in the makerspace during their breaks, or after classes. In some schools teachers could decide to let all their students to work on curriculum-related projects (in different subject areas, such as science, mathematics, technology, and music) using makerspace.

In all six schools, makerspace was located in a specific room, which could be a classroom (five schools) or a library (one school) but the activities could be organised in other spaces, as well. For instance, in one school there were three different spaces used for makerspace activity (including multimedia lab and art classroom). One school used two classrooms with the wall removed between them. One school used, along with the makerspace-classroom, few desktop computers in the classrooms (one of which was a classroom – Studio – two classrooms with a wall removed between them). All six makerspaces were equipped with a variety of programmable technologies, among them, 3-D printers, Arduino kits, and LEGO-robots. Students also had access to desktop computers with Scratch (for programming), Tinkercad (for 3-D design), Minecraft, and other multimedia production software. In some schools, students were using iPads (for example, for reading online tutorials), and depending on the school/grade level were asked to submit a formal proposal of the project they wanted to accomplish. This diversity is a common characteristic of makerspaces which was also noticed by Peterson and Scharber (2018), "makerspaces are all unique and the tools within them vary greatly" (p. 48). What is important, according to the authors is that while digital technologies, such as iPads, 3-D printers, and robots are not mandatory technologies for makerspaces, due to their low costs and accessibility they may “afford students additional mediums for making” (Idem.). The projects were chosen by students (sometimes guided by teachers), according to their interests and available technology.

Despite a variety of school settings, the ways in which the work in makerspaces was organized, and variety of projects and technologies students used, we found similarity across the teachers’ discourse about the experience, learning opportunities they observed, and possible gains for students. Namely, from the teaching and teachers’ perspective, we identified four common characteristics which reflect an innovator-teachers’ mindset in the sense it was described by Couros (2015).

The *first* commonality refers to **teacher’s desire to change their teaching** by implementing technology-based innovations. This seems to be an important factor which could be one that influenced participants’ choice to embrace makerspaces with their students. Almost all teacher-participants were previously engaged in some technology-based initiatives that incorporated laptops, social media, multimedia production, or robotics. Based on such experience, teachers developed a particular vision of learning with technology, skills students would be able to develop by using it, and importance of providing non-traditional learning opportunities for students. The significance of previous experience in teaching with technology was reported by Liu, Ritzhaupt, Dawson, and Barron (2017) as a variable which positively influences technology integration by K-12 teachers. Indeed, taking into account earlier studies about ICT integration in NB schools: introducing laptops (Blain et al., 2007) and robotics-based learning (Blanchard et al., 2010), we see in teachers’ desire to embrace maker movement their willingness in continuous search for new ways to teach as they believe, it would empower their students with new skills which they find important for students’ success in the future.

Second, the experience teachers were able to gain in integrating new technologies in their practice seems to have enabled them to be **resilient when dealing with several issues**: connecting maker activities to specific subject curricula, experimenting with new technology, collaborating with other stuff members, as well as experts from the community, and striving to maximize learning opportunities for their students. On one side, this finding seems to align with Liu et al.’s (2017) results about teachers’ comfort and confidence with technology as positively influencing technology integration. Moreover, some teachers we interviewed, did not feel as experts in all makerspace technologies their students work with. Yet, they seemed to be comfortable with not possessing enough knowledge, as they were confident that students will learn on their own, from their more knowledgeable peers, or with help from the experts from the community.

This strong disposition to using new technologies seems to lead to the *third* commonality which refers to the **student-centered approach** teachers adopt when guiding their students through making activities. While valuing diversity of students’ learning pathways these teachers seemed to focus on students’ interests, curiosity, and engagement thus creating a risk-free and caring atmosphere of success-oriented pedagogy, even if students’ projects remained a work-in-process enterprise. They guided students rather in an indirect way through discussion and collaboration when providing diversity of resources (e.g., online tutorials, resource kits), including help from experts from the community when needed. While the focus on responding to students' particular learning needs and accepting a diversity of learning paths seems to remain central in makerspaces teachers' discourse, there are some pre-cursors of perceptions going beyond curricular concerns towards recognition of changing essence of school culture as a whole, a trend described in the recent paper by Tan (2018). According to Tan, it consists in "a significant ludic component…, highly authentic scientific practices…[and] attention to tacit knowledges in learning the practices of science" thus challenging existing curriculum goals which need to be "reimagined" (idem., p. 1).

This last remark is also related to the *fourth* finding which refers to the **complexity of assessment of students' work** in makerspaces that we already noticed in the context of robotics-based learning studies (Savard & Freiman, 2016). While the projects students realize in makerspaces are connected to several transdisciplinary and interdisciplinary skills, it is not yet clear what the student learning outcomes are in makerspaces and how to evaluate them. Teachers we interviewed in this study seem to value rather informal methods which showcase students' achievement (project presentations, exhibitions, fares, etc.) In the literature, we find indications that this helps students to acquire and develop new skills (sometimes called soft– or twenty-first century skills), which are also associated with integrated view of education now labeled as STEM, STEAM, STEEAM (the latter includes the second 'E', which stands for Entrepreneurship) education. This type of 'life-skills' would help them build their careers in hi-tech-related areas and beyond (Hui & Gerber, 2017; Miller, 2017). Other points that require more discussion are relationships between disciplinary skills (old-basic) and so-called new literacies. Also, there is a hope that makerspaces will help students to find and develop their particular interests and strengths that often fall beyond the regular schooling.

The teachers from six school we had a chance to interview seem to know how to turn this vision into their practice – in addition to being engaged in exploring new learning opportunities for their students, they also trust their students' capacity to respond to challenges that working in makerspaces represent. The approach the teachers seem to apply in makerspaces is labeled by Voigt, Mair, and Unterfrauner (2018) as 'tinkering' approach (as opposed to one known as 'instructional)'. Referring to Resnick and Rosenbaum (2013), who characterise this method as "playful", "experimental", and "iterative" style of engagement, Voigt et al. (2018) recognize difficulties that educational institutions face when trying to implement it in practice.

Being a relatively new phenomenon in the NB K-12 school system, makerspaces provide an interesting example of how teaching and teachers embrace the twenty-first century learning. While clearly connected, although in a rather indirect way, to the newest provincial strategic 10-Years Plan (GNB, 2016), the concept of makerspaces might contribute to its main vision, one of the developing and realizing each student's potential. More specifically, the projects students realize could help them to develop competences they need to achieve their career and life readiness plan in terms of identifying their strengths and areas of interest (objective 1 of the

Plan). In connection to the STEM education, the makerspaces might contribute to developing reasoning and problem-solving skills, as well as to nurturing children's creativity (objective 7 of the Plan). However, the Plan does not provide a clear mechanism of integrating this type of education into curriculum. There is therefore a need for future investigations of how new learning spaces (in the case on this chapter, makerspaces) could contribute to the development of those skills.

Besides searching for connections to curriculum and strategic educational plan, and grasping the essence of maker pedagogy, our study contributes to deeper understanding of important paradigm shifts in learning which are described, among other authors, by Roffey, Sverko, and Therien (2016). According to the authors, this pedagogy is grounded in Papert's (1980) constructionist philosophy. Namely, it stresses the importance of media, tools, and contexts for human development while helping individuals to make sense of their experience, emphasises culture of creating as base of this experience (Roffey et al., 2016, pp. 8–9). Moreover, there is an essential part of this culture which is a participatory, real-life oriented, problem-based, collaborative, and open-ended inquiry: "This is not the project done at the end of a unit of learning, but the actual vehicle and purpose of the learning" (idem, p. 9).

The example of makerspaces our team just began to study points at several aspects of this approach which seem to be valued by the pioneering teachers in NB schools: pluralism of learning paths, experience of creating tangible learning objects, adapting solutions to changing conditions, and overall a different way of accessing STEM problems (Voigt et al., 2018). Digging deeper in data discussed in this chapter would help in further refining our collective understanding of this novel philosophy of teaching and learning for the twenty-first century.

Acknowledgements This study was conducted with the help of the Canadian Social Sciences and Humanities Research Council (Partnership Development Grant #890-2013-0062). We also thank Brilliant Labs, our partner, and participating school districts, schools and teachers for their continuous support and collaboration in this research.

References

Adcock, J. (2018). *Disrupt a space. Makerspace*. Retrieved from http://www.innovatemyschool.com/ideas/disrupt-a-space-makerspace

Blain, S., Beauchamp, J., Essiambre, C., Freiman, V., Lirette-Pitre, N., Villeneuve, D., …, Manuel, D. (2007). *Les effets de l'utilisation des ordinateurs portatifs individuels sur l'apprentissage et les pratiques d'enseignement.* Centre de Recherche et de Développement en Éducation. Université de Moncton. Retrieved from https://www.umoncton.ca/crde/files/crde/wf/wf/pdf/Projets/rechercheportatif.pdf

Blanchard, S., Freiman, V., & Lirette-Pitre, N. (2010). Strategies used by elementary schoolchildren solving robotics-based complex tasks: Innovative potential of technology. *Procedia - Social and Behavioral Sciences, 2*(2), 5686–5692.

Blikstein, P. (2013). Digital fabrication and 'making' in education: The democratization of invention. In J. Walter-Herrmann & C. Büching (Eds.), *FabLabs: Of machines, makers and inventors*. Bielefeld, Germany: Transcript Publishers.

Brilliant Labs. (2017). *Labos créatifs* [Brilliant Labs]. Retrieved from https://www.brilliantlabs.ca/about-us

Chiasson, M., & Freiman, V. (2017). Closing the gap: How can the school system embrace the age of acceleration? In J. Johnston (Ed.), *Proceedings of EdMedia 2017* (pp. 615–620). Washington, DC: Association for the Advancement of Computing in Education (AACE). Retrieved from https://www.learntechlib.org/primary/p/178369/

Couros, G. (2015). *The innovator's mindset: Empower learning, unleash talent, and lead a culture of creativity*. San Diego, CA: Dave Burgess Consulting Inc.

Dewey, J. (1916). *Democracy and education: An introduction to the philosophy of education*. New York: Macmillan.

Djambong, T., Freiman, V., Gauvin, S., Paquet, M., & Chiasson, M. (2018). Measurement of computational thinking in K-12 education: The need for innovative practice. In D. Sampson, D. Ifenthaler, J. M. Spector, & P. Isaías (Eds.), *Digital technologies: Sustainable innovations for improving teaching and learning*. Cham, Switzerland: Springer.

Freiman, V., Godin, J., Larose, F., Léger, M., Chiasson, M., Volkanova, V., & Goulet M. J. (2017). Towards the life-long continuum of digital competences: Exploring combination of soft-skills and digital skills development. D. D. Marti (dir.), *Proceedings of the 11th annual international technology, education and development conference, INTED2017* (pp. 9518–9527). Valencia, Spain: International Academy of Technology, Education and Development (IATED).

Freiman, V., Larose, F., Chukalovskyy, R., LeBlanc, M., Léger, M., Bourgeois, Y., & Godin, J. (2016, July 4–7). Defining and developing life-long digital competencies: Partnership building approach. *Proceedings of the EDULEARN 2016 international conference*, Barcelona, Spain.

Freiman, V., & Lirette-Pitre, N. (2007). PISA 2000 case study: New Brunswick. In: Arbeitsgruppe Internationale Vergleichstudie (Hrsg.). *Shullleistungen und Steurung des Scholsystems in Bundesstaat: Kanada und Deutschland in Vergleich* (pp. 339–362). Muenster, Germany/New York, NY/Muenchen, Germany/Berlin, Germany: Waxmann.

Galway, G., & Gill, D. (2018). *Making time for makerspaces: Teaching through making.* https://canadianteachermagazine.com/2018/01/18/making-time-for-makerspaces-teaching-through-making/

Gershenfeld, N. (2012). How to make almost anything. The digital fabrication revolution. *Foreign Affairs, 91*(6), 43–57.

Gerstein, J. (2016). *Learner empowerment.* Retrieved from https://usergeneratededucation.wordpress.com/2016/02/13/learner-empowerment/

Gilbert, J. (2017). Educational makerspaces: Disruptive, educative or neither? *New Zealand Journal of Teachers' Work, 14*(2), 80–98.

Government of New Brunswick. (1992). Commission on Excellence in Education: Schools for a New Century. Fredericton, NB.

Government of New Brunswick. (2000). *Let's discuss public education governance...* Retrieved from https://www.gnb.ca/legis/business/committees/reports/pub-edu-gov-e.asp

Government of New Brunswick. (2008). Retrieved from https://www2.gnb.ca/content/gnb/en/news/news_release.2008.05.0657.html

Government of New Brunswick. (2016). *Everyone at their best*. Retrieved from https://www2.gnb.ca/content/dam/gnb/Departments/ed/pdf/K12/EveryoneAtTheirBest.pdf

Hagel, J., Brown, J. S., & Kulasooriya, D. (2014). *A movement in the making.* Westlake, TX: Deloitte University Press. Retrieved from http://dupress.com/articles/a-movement-in-the-making/

Hughes, J. (2017). *Meaningful making. Establishing a makerspace in your school or classroom* (Research monograph). Retrieved from http://www.edu.gov.on.ca/eng/literacynumeracy/inspire/research/meaningful_making_en.pdf

Hui, J. S., & Gerber, E. M. (2017, February 25–March 1). *Developing makerspaces as sites of entrepreneurship*. CSCW 2017, Portland, OR, USA, pp. 2023–2038,

Lave & Wenger. (1991). *Situated learning: Legitimate peripheral participation*. New York, NY: Cambridge. University Press.

Levesque, R. (2011). *École communautaire entreprenariale: Clé indispensable au développement durable*. http://rccfc.ca/congres_11/2011-03_Ecole_communautaire_Rino-Levesque.pdf

Léger, M. T., & Freiman, V. (2018). *Learning to be creative: A causal-comparative study of digital skill development in a technology-rich classroom.* Paper presented at the 2018 AERA Annual Meeting, New York, NY, USA.

Litts, B. K. (2015). *Making learning: Makerspaces as learning environments.* Doctoral dissertation, University of Wisconsin-Madison, Madison, WI, USA.

Liu, F., Ritzhaupt, A. D., Dawson, K., & Barron, A. E. (2017). Explaining technology integration in K-12 classrooms: A multilevel path analysis model. *Educational Technology Research and Development, 65*(4), 795–813. https://doi.org/10.1007/s11423-016-9487-9

Love, S.-L. (2015). *4C's model: Critical thinking, creative thinking, collaboration, communication*. http://www.eschoolnews.com/files/2015/09/The-Four-Cs.pdf

Maker Media. (2013). *The makerspace playbook: School edition*. Retrieved from http://makered.org/wp-content/uploads/2014/09/Makerspace-Playbook-Feb-2013.pdf

Martin, L. (2015). The promise of the maker movement for education. *Journal of Pre-College Engineering Education Research, 5*(1), 30–39.

Martinovic, D., & Freiman, V. (2013). *Digital skills development for future needs of the Canadian labour market* (pp. 1–71). Final report to the Social Sciences and Humanities Research Council, Ottawa, ON, Canada.

MEDPE. (2016). *Programme de mathématiques*. Cadre théorique commun M-12. Fredericton, NB, Canada.

Miller, J. (2017). Mapping elementary and middle school makerspace environments to curriculum content through STEAM (science, technology, engineering the arts, and mathematics) challenge cards. In P. Resta & S. Smith (Eds.), *Proceedings of society for information technology & teacher education international conference* (pp. 1357–1364). Austin, TX: Association for the Advancement of Computing in Education (AACE). Retrieved from https://www.learntechlib.org/primary/p/177419/

Milton, P. (2008). *A review of New Brunswick's dedicated notebook research project one-to-one computing – A compelling school-change intervention*. Canadian Education Association. Retrieved from https://www.edcan.ca/wp-content/uploads/cea-2008-hp-notebook-report-nb.pdf

Montessori, M. (1912). *The Montessori method*. New York: Frederick A. Stokes Company.

Niederhauser, D. S., & Schrum, L. (2016, October 28–30). *Enacting STEM education for digital age learners: The "maker" movement goes to school.* Paper presented at the International Association for Development of the Information Society (IADIS) International conference on cognition and exploratory learning in the digital age (CELDA) 13th, Mannheim, Germany, pp. 357–360. Retrieved from https://files.eric.ed.gov/fulltext/ED571396.pdf

NBDE. (2006). *New Brunswick Department of Education: Guidelines and Procedures for Career Exploration 110 and Copperative Education 120*. https://www2.gnb.ca/content/dam/gnb/Departments/ed/pdf/K12/curric/Coop/GuidelinesAndProceduresCareerExploration110CoopEducation120.pdf

Oliver, K. M. (2016). Professional development considerations for makerspace leaders, Part one: Addressing "what?" and "why?". *TechTrends: Linking Research and Practice to Improve Learning, 60*(2), 160–166.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. New York, NY: Basic Books.

Peppler, K., & Bender, S. (2013). Maker movement spreads innovation one project at a time. *Phi Delta Kappan, 95*(3), 22–27. https://doi.org/10.1177/003172171309500306

Peppler, K., Keune, A., Xia, F., & Chang, S. (2014). *Survey of assessment in makerspaces* (Research Brief 17). Retrieved from http://makered.org/wp-content/uploads/2018/02/MakerEdOPP_RB17_Survey-of-Assessments-in-Makerspaces.pdf

Peterson, L., & Scharber, C. (2018). Learning about makerspaces: Professional development with K-12 inservice educators. *Journal of Digital Learning in Teacher Education, 34*(1), 43–52.

Piaget, J. (1956). *The origins of child intelligence*. New York, NY: International University Press.

Quinton, S., & Smallbone, T. (2010). Feeding forward: Using feedback to promote student reflection and learning: A teaching model. *Innovations in Education and Teaching International, 47*, 125–135. https://doi.org/10.1080/14703290903525911

Ravipati, S. (2017). Report: Makerspaces, coding, robotics pick up momentum in schools. https://thejournal.com/articles/2017/09/05/report-makerspaces-codingrobotics-pick-up-momentum-in-schools.aspx

Resnick, M., & Rosenbaum, E. (2013). Designing for Tinkerability. In M. Honey & D. Kanter (Eds.), *Design, make, play: Growing the next generation of STEM innovators* (pp. 163–181). Routledge.

Roffey, T., Sverko, C., & Therien, J. (2016). *The making of a makerspace: Pedagogical and physical transformations of teaching and learning*. Vancouver, BC: University of British Columbia.

Savard, A., & Freiman, V. (2016). Investigating complexity to assess students' learning in a robotics task. *Digital Experiences in Mathematics Education, 2*(2), 93–114.

Sheridan, K., Halverson, E. R., Litts, B., Brahms, L., Jacobs-Priebe, L., & Owens, T. (2014). Learning in the making: A comparative case study of three makerspaces. *Harvard Educational Review, 84*(4), 505–531.

Tan, M. (2018). When makerspaces meet school: Negotiating tensions between instruction and construction. *Journal of Science Education and Technology*. https://doi.org/10.1007/s10956-018-9749-x

Voigt, C., Mair, S., & Unterfrauner, E. (2018). Hacking the knowledge of maker communities in support of 21st century education. In S. Bodrunova (Ed.), *Internet science* (INSCI 2018. Lecture notes in computer science, vol 11193). Cham, Switzerland: Springer.

Vongkulluksn, V. W., Matewos, A. M., Sinatra, G. M., & Marsh, J. A. (2018). Motivational factors in makerspaces: A mixed methods study of elementary school students' situational interest, self-efficacy, and achievement emotions. *International Journal of STEM Education, 5*(1), 43. https://doi.org/10.1186/s40594-018-0129-0

Vygotsky, L. (1978). *Mind and society*. Cambridge, MA: Harvard University Press.

Wardlow, L., & Harm, E. (2015). Using appropriate digital tools to overcome barriers to collaborative learning in classrooms. *Educational Technology, 55*(3), 32–35.

Viktor Freiman (Ph.D.) is a full professor of mathematics education at the Université de Moncton, Faculty of Educational Sciences, Canada. His research projects look into leveraging of creative potential in mathematics using technology. He is co-editor of Springer book Series *Mathematics Education in the Digital Era*, recently co-edited two books, *Creativity and Technology in Mathematics Education* and *History of Computation and Computing Devices*. He leads CompeTI.CA partnership network to study ICT competences in the Atlantic Canada, among them, STEM competences and learning and teaching in makerspaces. Other areas of expertise are mathematical giftedness, problem solving, teaching and learning algebra in early grades, inter- and transdisciplinary connections of mathematics.

The Influence of teacher’s Orchestration Using a Novel System for Advancing Group Learning on Students’ Conceptual Learning – The Case of a Geometry Lesson

Naomi Prusak, Osama Swidan, and Baruch Schwarz

1 Introduction

During lessons in which students are arranged in several groups in order to collaboratively solve a learning task, teachers face many challenges, from when providing guidance that takes into consideration the variance between students and groups, up to establishing norms of collaboration. The teacher should monitor all the learning groups, and make sure that all the students are progressing and achieving the intended pedagogical goals. We use the term ‘should’ because this monitoring has been considered so far as impracticable. The difficulties of adapting teaching to the special needs of all students in the classroom context, especially when students collaborate in several groups simultaneously, has occupied scholars for many years. This kind of almost impossible activity has been called *orchestration.* Dillenbourg (2013) defined orchestration as “how a teacher manages, in real time, multi-layered activities in a multi-constraints context.” (ibid, p. 485). In his pioneering research, Dillenbourg has suggested that dedicated technologies may turn orchestration to a practicable classroom activity.

The depicted study investigated the influence of teacher’s guidance practices using a Computer-Supported Collaborative Learning (CSCL) tool on students’ learning processes. In our attempts to cope with the challenges mentioned above, we used advanced technological tools to facilitate the teachers’ orchestrating processes. To this end, we developed a System for Advancing Group Learning in Educational Technologies (SAGLET). This system was designed to support teachers’ orchestration of several learning groups. The system simultaneously displays

---

N. Prusak (✉) · B. Schwarz
The Hebrew University of Jerusalem, Jerusalem, Israel
e-mail: inlrap12@netvision.net.il

O. Swidan
The Ben Gurion University of the Negev, Beer-Sheva, Israel

Y. Ben-David Kolikant et al. (eds.), *STEM Teachers and Teaching in the Digital Era*, https://doi.org/10.1007/978-3-030-29396-3_16

on a computer screen several virtual rooms in which the students are working—we elaborate about the SAGLET in Sect. 3.

Schwarz, Prusak, Swidan, Livny, and Gal (2018) who investigate the use of SAGLET in authentic classroom settings,[1] identified several key moments during the learning process of the students. The authors defined them as *critical moments* –“moments in which the teacher’s (lack of) intervention may lead to a particular development (positive or negative) at the epistemic level regarding the shared object” (p. 3). For example, if the teacher notices that a group of students is idle, she/he may decide to intervene (say, by asking the group whether they are having problems, or simply by asking the group to be active). Schwarz et al. posited that if the teacher is aware of these moments, she/he may act on the fly to increase the productivity of the interaction. In their study, they found five types of intervention in response to these critical moments: (a) encouraging collaboration among group members; (b) monitoring and supervising the execution of a task; (c) asking for justifications; (d) scaffolding argumentation; and, (e) social validation.

In Schwarz et al. (2018) study, the researchers focused on the teacher’s actions. However, the effects of these interventions on the student learning were not addressed. In this chapter, we aim to fill this gap, namely to examine whether teachers’ interventions boost the student learning. More specifically, we investigate whether teaching interventions through the SAGLET system boost conceptual learning in geometry.

2 Theoretical Background

2.1 Collaborative Learning

Collaborative learning, one of the twenty-first century skills, is now incorporated in international standardized tests, such as The Programme for International Student Assessment (PISA) tests. For this project, we adopted Roschelle and Teasley’s (1995) definition of collaboration, as “coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem” (p. 70). The ethical aspect of collaboration—the fact that people learn to coordinate actions and eventually to help each other, bestow to collaborative learning a genuine educational vision. In addition, collaborative settings may entail active engagement of participants in their learning processes.

However, the implementation of collaborative practices in schools is often problematic. As noted by Webb (1991, 1995), arranging students in small groups rarely leads them to collaborate, even when students are given scripts or instructions in advance for collaborating. Other researchers developed strategies that advanced

---

[1] The experiment was conducted in a classroom setting; Communication among students, and between students and the teacher, occurred in an on-line mode.

collaboration (e.g., Crouch & Mazur, 2001) though, but they still recognize that managing collaborative learning in classes is a serious challenge for instructors.

CSCL researchers have identified the importance of task design for boosting collaboration. Prusak, Hershkowitz, and Schwarz (2012) proposed three principles for task design to encourage productive collaborative learning processes: (a) creating a situation of conflict; (b) creating a collaborative situation, and (c) providing tools for raising and checking hypotheses. They showed that these principles triggered collaboration and argumentation among students. Designed tasks and CSCL affordances are not sufficient, though, for encouraging deep and collaborative learning, and teachers' guidance is necessary and cannot be overlooked (Rummel & Spada, 2005).

2.2 Teacher Orchestration in Mathematics

Engaging mathematics students in active exploration and inquiry processes are major challenges for teachers. It requires a shift in the teacher's role from lecturing and telling, to listening, observing, facilitating, and guiding (Drijvers, Doorman, Boon, Reed, & Gravemeijer, 2010). Teachers take a significant role in guiding the development of mathematical discourse ensuring all students actively participate. The teachers conducting inquiry activities in the classroom should orchestrate and facilitate the classroom discourse (McCrone, 2005). In the role of facilitator, the teacher leads shifts in the discourse, ensuring that it is conceptually focused and reflective. Kazemi (1998) illustrated how discourse promoting conceptual reasoning was achieved through specific pedagogical actions. These included pressing students to provide conceptually focused justification for mathematical actions, asking questions, and raising and checking hypotheses.

The introduction of technological tools into educational settings have challenged teachers' roles in managing student learning practices. To take full advantage of technology in teaching practices, the role the teacher plays in classrooms is critical and must be taken into account when designing technology-enhanced learning environments. To shed light on the ways teachers use technological tools in their classrooms, Drijvers et al. (2010) investigated which types of orchestration teachers develop when they use technology, but they dealt with the use of computers in conventional settings. Schwarz et al. (2018) investigated orchestration practices in an innovative environment (the SAGLET system described in Sect. 3), which was designed to boost learning by the use of synchronous communication of students collaborating and arguing when they work in several groups simultaneously. This kind of orchestration is impracticable without technological aids, as teachers cannot jump from one group to the other to help in conceptual learning. Schwarz et al. (2018) showed that teachers' interventions through SAGLET mostly invited collaboration and argumentation processes among students. Built on the study of Schwarz et al., we examine the effectiveness of orchestrating several groups learning simultaneously, which rarely has been checked.

2.3 Argumentation in Mathematics

Argumentation is an important activity in learning and teaching mathematics in general, and geometry in particular. Argumentative processes help students to shift from informal to formal mathematics, which is characterized by its deductive structure. While the term "argumentation" is multifaceted, we adopt here Baker's definition (2003), who sees "argumentative interaction fundamentally as a type of dialogical or dialectical game that is played upon and arises from the 'terrain' of collaborative problem solving, and that is associated with *collaborative meaning-making*" (p. 48, the emphasis is original). While the dialogue refers to a conversation between two or more entities, dialectic means a dialogue in which two (or more) contradicting or parallel ideas take place, so it refers to exchange of arguments and counter-arguments. These processes are very important for learning mathematics because mathematical processes involve proofs and refutations (Lakatos, 1976; De Villiers', 2010).

2.4 Argumentation in Geometry and the Use of Dynamic Geometry Environments (DGE)

The role of argumentation is central in learning geometry. While learning geometry, students are required to give reasons for claims they raise and to find warrants to justify the claims. Recently, many researchers and mathematics educators see the role of proof in classroom mainly as a *convincing argument* and *explanation* (Hanna, 1990; Boero, 2008). According to Hadas, Hershkowitz, and Schwarz (2001), the processes of reasoning in geometry include **intuitive** elements as well as **visual** elements, which require **creativity** and **experimental methods.** Therefore, teaching geometry should encourage the adoption of experimental learning methods and implementation of inquiry techniques. An activity which demands from the students to provide evidence, explain and reason to confirm or refute the claims, is an activity that invites the use of **intuition, visualization,** and **trial and error** modes of investigation.

Dynamic Geometry Environments (DGEs) afford the ingredients necessary for efficient geometry reasoning; they allow 'dragging' on-screen objects to produce a variety of diagrams that can help students to refute conjectures and visualize proofs (Arzarello, Olivero, Paola, & Robutti, 2008; Sinclair & Robutti, 2013; Ng & Sinclair, 2015). However, the literature on DGEs did not focus on a setting in which several groups work simultaneously. In this chapter, we used a DGE to tackle a difficult issue in geometry learning—inclusion relations in quadrilaterals, in a context of orchestration.

2.5 *Inclusion Relations in Quadrilaterals*

Several studies have shown that many students have problems with the inclusion relationships between quadrilaterals (e.g., Fujita & Jones, 2007). By ‘inclusion relationship’ we mean the classification of a set of concepts in such a manner that the more particular concepts create subsets of the more general ones. Teaching the inclusion relationship of quadrilaterals helps in promoting the development of geometrical thinking (Fujita & Jones, 2007). According to de Villiers (1994), there are some important functions of this inclusion relationship: (a) It simplifies the deductive systematization and derivation of the properties of more special concepts; (b) It often provides a useful conceptual schema during problem solving; and (c) It sometimes suggests alternative definitions and new propositions. For example, to justify why a square is a kite, learners need to be able to examine its properties. The fact that a square has more properties than a kite should not impinge on the right answer. However, in everyday reasoning, it does; children find it difficult to distinguish between critical and non-critical properties (Erez & Yerushalmy, 2006). Several researchers observed that DGEs offer great potential for conceptually enabling many children to see and accept the possibility of the inclusion relationship of quadrilaterals; for example, by dragging the vertices of a dynamic parallelogram to transform it into a rectangle, a rhombus, or a square (Jones, 2000; Fujita & Jones, 2007).

3 The SAGLET System and Its Integration with the Virtual Math Team Software

SAGLET (see Fig. 1) is a technological tool, which supports collaborative and argumentative learning within or between classrooms. Various technologies have been developed to support small-group learning in isolated activities. These technologies

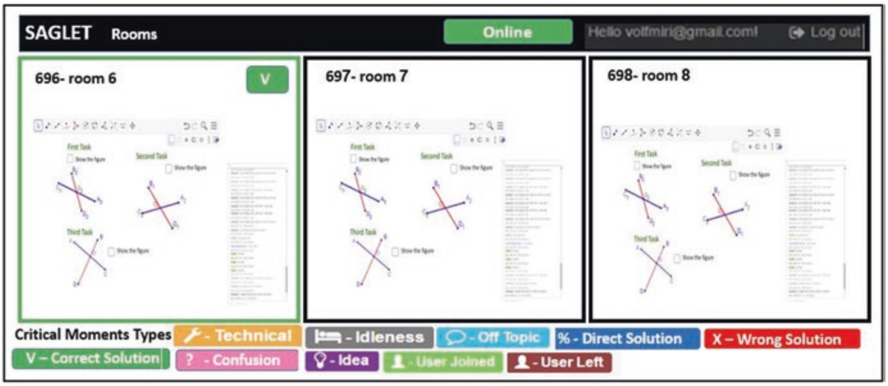


Fig. 1 SAGLET interface with three virtual rooms

are rarely used in schools, though. When classes are arranged in several small groups working simultaneously (in the same classroom or at different sites), teachers are generally unable to identify critical moments. SAGLET uses AI techniques to provide information about critical moments in the groups' working. SAGLET augments on-line learning environments to include technologies with the ability to (1) use educational software to recognize critical moments of emergent learning in groups that are interacting and (2) present salient information to teachers visually. SAGLET provides a set of alerts that the instructor may use to orchestrate multiple groups engaging simultaneously in a learning task. Although the provision of critical moments seems *a priori* useful for teachers, great caution is necessary for using alerts in learning-teaching situations. Alerts may function as distractors for teachers who are busy helping specific groups.

We integrated SAGLET with the Virtual Math Team (VMT) software (Stahl, 2009), which includes a GeoGebra applet shared by all participants and offers them the opportunity to collaborate on geometrical tasks (Stahl, 2009). Figure 2 displays an inquiry space in which small groups can share explorations and co-construct geometric figures (Part a). When one participant drags or constructs a geometrical shape, the others can see the changes of the shape. VMT also provides a chat window (Part b), in which students can write ideas, share them with their peers, and coordinate actions. Students can scroll up and down to return to previous chats.

SAGLET allows teachers to observe on-line the work of groups of students engaged in learning tasks with VMT in different virtual rooms and to intervene whenever they deem appropriate. SAGLET enables to follow simultaneously several virtual rooms and display these rooms on the teacher's interface. As learners progress in their group work, SAGLET informs the teacher of critical moments. Figure 3 shows an example of windows observable by the teacher. In this case, the

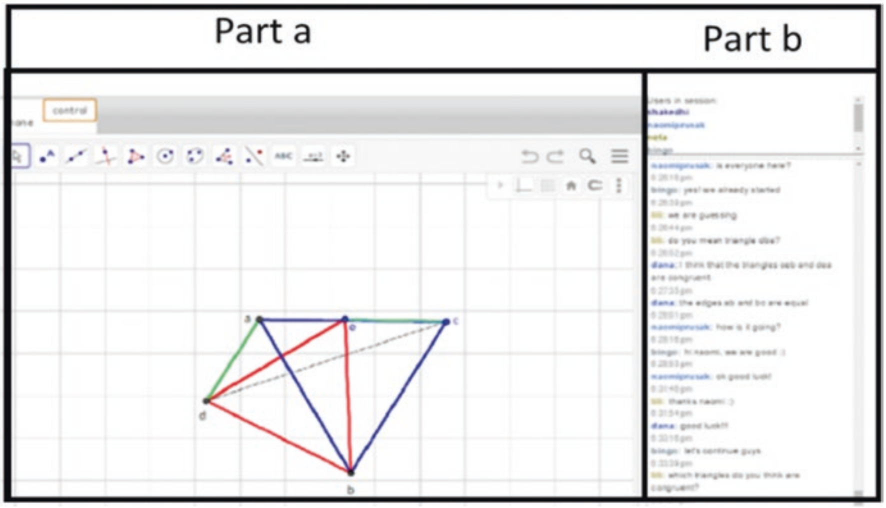


Fig. 2 Virtual Math Team (VMT) interface consisting of GeoGebra applet and chat screen

Fig. 3 The teacher is informed of a correct solution in one room and a technical problem in another room

teacher is informed of a correct solution in room 696 and a technical problem in room 697. Alerts are easily visible as colored frames. The teacher can disregard them, may enter the room specified by the alert, and may decide to intervene, which we deem the main innovation of SAGLAT.

4 Research Question and Setting

In a previous research (Schwarz et al., 2018) showed that teachers were able to use the SAGLET system to monitor the work of several groups simultaneously and to intervene when deemed necessary. Schwarz et al., identified five types of teacher's intervention. Yet, the effect of the teacher's intervention on student learning in a collaborative synchronic environment was not addressed. In the current research, we aim to fill this gap. Doing so, we asked the following research question: What do the student gain from the teacher's interventions using in the SAGLET-facilitated learning environment?

5 The Research Study

The research team developed a learning unit dealing with the inclusion relationship of quadrilaterals appropriate for Grade 5 students. The teacher, who was familiar with the VMT software, instructed the students how to use it. The VMT software supports **collaborative learning**, as the students investigate the topics in the unit and discuss them. In addition, they were instructed how to carry out basic actions in GeoGebra software—a DGE enabling geometric investigations. The study included 15 lessons over a duration of 5 weeks. The research team instructed the teacher how to use effectively the SAGLET system during three 60 min. sessions.

5.1 Participants

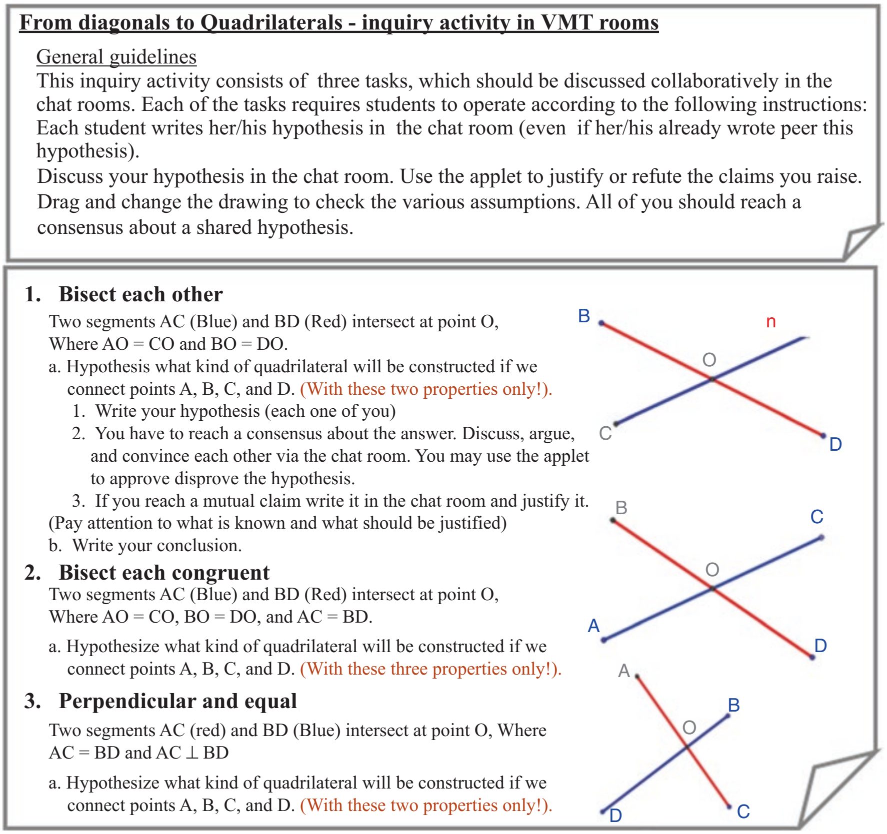
Nineteen students from Grades 5 and 6, chosen on a voluntary basis, participated twice a week in an enrichment program in mathematics during school hours. The 2 h were supplementary to the regular weekly lessons. The students who chose to participate in the enrichment program were all high achievers in mathematics. The two lessons of the enrichment program took place either at the computer lab (when computers were needed), or in the classroom dedicated to high achievers. Myra (a pseudonyms), the teacher was an experienced mathematics teacher with 10 years of seniority. She also served as a pedagogical counsellor in pre-service programs for mathematics teachers.

5.2 Procedure

The experiment took place in a computer room. Each student sat by one computer and at the same time was a member of a math team located in a "virtual room", with one or two of his/her peers. It is noteworthy that the members of each room were sitting apart from each other. The teacher asked them not to talk. Rather, they were invited to write their claims in the chat window of the VMT system. The teacher explained that by doing so, she could look at whatever they write and would be able to help them when needed. The teacher distributed to each student a booklet with three tasks (see Fig. 3) as well as a collaborative script—specific instructions on how to collaborate with peers and a requirement to reach consensus about the solution (see the abridged version of these instructions in the general guidelines in Fig. 3). Other instructions encouraged students to argue with each other, to justify their claims, and to try to refute the claims of their peers in case they disagreed with them. After been given the booklet, the students in each room were invited to solve the three tasks in a 90 min session.

5.3 Task Design

In Fig. 4, we present an abridged version of the three tasks that we designed for Grade 5 students. There are some general guidelines about the procedures the students needed to do in all three tasks. These general guidelines were aimed to create conditions for collaboration and for encouraging to hypothesize, argue, and convince or be convinced by the others. The three tasks in Fig. 3 explore the inclusion relationship of quadrilaterals. In Task 1, students are asked which kind of quadrilateral fits the property of having diagonals that bisect each other (with this property only). The answer is a parallelogram. In Task 2, the two properties of equal and



From diagonals to Quadrilaterals - inquiry activity in VMT rooms

General guidelines
This inquiry activity consists of three tasks, which should be discussed collaboratively in the chat rooms. Each of the tasks requires students to operate according to the following instructions: Each student writes her/his hypothesis in the chat room (even if her/his already wrote peer this hypothesis).
Discuss your hypothesis in the chat room. Use the applet to justify or refute the claims you raise. Drag and change the drawing to check the various assumptions. All of you should reach a consensus about a shared hypothesis.

1. **Bisect each other**

Two segments AC (Blue) and BD (Red) intersect at point O,
Where AO = CO and BO = DO.
a. Hypothesis what kind of quadrilateral will be constructed if we connect points A, B, C, and D. (With these two properties only!).
   1. Write your hypothesis (each one of you)
   2. You have to reach a consensus about the answer. Discuss, argue, and convince each other via the chat room. You may use the applet to approve disprove the hypothesis.
   3. If you reach a mutual claim write it in the chat room and justify it.
(Pay attention to what is known and what should be justified)
b. Write your conclusion.

2. **Bisect each congruent**

Two segments AC (Blue) and BD (Red) intersect at point O,
Where AO = CO, BO = DO, and AC = BD.
a. Hypothesize what kind of quadrilateral will be constructed if we connect points A, B, C, and D. (With these three properties only!).

3. **Perpendicular and equal**

Two segments AC (red) and BD (Blue) intersect at point O, Where AC = BD and AC ⊥ BD
a. Hypothesize what kind of quadrilateral will be constructed if we connect points A, B, C, and D. (With these two properties only!).

Fig. 4 An abridged version of the three tasks

bisecting diagonals fit rectangles (hence, answering that the family of squares is the solution is a wrong answer because it limits the answer to a subfamily). In Task 3, the two properties are that the diagonals are equal and perpendicular. The answer is that many quadrilaterals have these properties; hence, these properties do not characterize any well-known family of quadrilaterals. All these tasks are difficult. They require the third level of abstraction according to the van Hiele levels of geometry understanding (van Hiele, 1986). The second and third tasks challenge students' reliance on stereotypes (Hershkowitz, 1990); young students generally misidentify the fits of rectangles and squares in Task 2, and squares or kites for Task 3. In addition, Task 3 provides an additional challenge —the uncommon answer in school learning that there are many unfamiliar kinds of quadrilaterals.

5.4 Data Collection

The complete activities of the teacher and the students were video-recorded with the CAMTASIA package, which captured computer screens during the sessions. Furthermore, we uploaded the logs of the students' and the teacher's chats from the VMT software. The student and the teacher work were conducted in Hebrew and the transcription was translated into English.

5.5 Analysis of the Data

To analyze the data, we focused mainly on the students' responses to the teacher's interventions. We analyze all teacher's interventions—in total, 103 interventions with all groups. We categorized them according to the five types of interventions mentioned in Schwarz et al. (2018): (A) encouraging collaboration among group members; (B) monitoring and supervising the execution of the task; (C) asking for justifications; (D) scaffolding of learning processes; and (E) social validation.

Following the categorization of the teacher's interventions, we used conventional content analysis (Hsieh & Shannon, 2005) to analyze the students' learning gains from these interventions. We present episodes demonstrating instances of these types of intervention and their impact. The first and second authors of this article independently analyzed the data. Thereafter, they discussed their separate analyses and reached consensus about the results presented in the next section.

6 Results

In this section, we review the types of interventions and their frequencies. In addition, we present episodes that illustrate the student gains following the intervention. Table 1 summarizes the teacher interventions according to the five type of interventions.

In total, we found 103 interventions in three virtual rooms. Their repartition was as such: 42 (41%) scaffolding of learning processes (Type D); 25 (24%), monitoring

Table 1 Distribution of the teacher interventions according to the five categories

Type of intervention	Room 696	Room 697	Room 698	Total
A	2	1	4	7
B	7	6	12	25
C	8	2	3	13
D	16	15	11	42
E	5	3	8	16
				103

and supervising the execution of the task (Type B); 16 (15.5%), social validation (Type E); 13 (12.5%), asking for justifications (Type C); and only seven (7%), encouraging collaboration among group members (Type A).

6.1 Encouraging Collaboration Between Group Members

The teacher observed that three students do not collaborate and each one of them is writing their own ideas without corresponding their peers. The teacher decided to intervene. This episode illustrates how the students collaborated to solve the task, after the teacher's intervention.

1. Teacher You should work together
2. Yishai We all think it is a parallelogram.
3. Gilad Yishai, what do you think? And what about you, Itamar?
4. Itamar [*Drags the figure for 5 s*] yes it's a parallelogram. Gilad what do you think?
5. Gilad Yes, it is a parallelogram.

In (1), the teacher requested the students to work in collaboration in order to solve the task. Yishai's use of the pronoun 'we' suggests that they are collaborating. Yet, Gilad took the lead of the group and asked each one of his peers to make sure that the decision about the answer is acceptable to everyone. Itamar dragged the figure to verify the correctness of the answer. Gilad, who was observing Itamar's dragging action, supported the claim. The usage of pronouns 'we', the leadership of Yishai, his referring to others, and the exploration of Itamar, suggest that the students engaged in a collaborative activity, after the teacher's encouragement to collaborate.

6.2 Monitoring and Supervising the Execution of the Task

Figure 5 displays the screenshots of the learning environment the students interacted with. All three tasks were presented simultaneously on the same screen. In this case, the teacher could observe and monitor the task the students were working on. The teacher noticed that one of the students dragged the figure that belongs to the third task while they were supposed to work on the first one.

The following episode illustrates how the teacher's interventions helped the students who, at the beginning, were not focusing on the intended item, to focus on the desired task and start the inquiry processes.

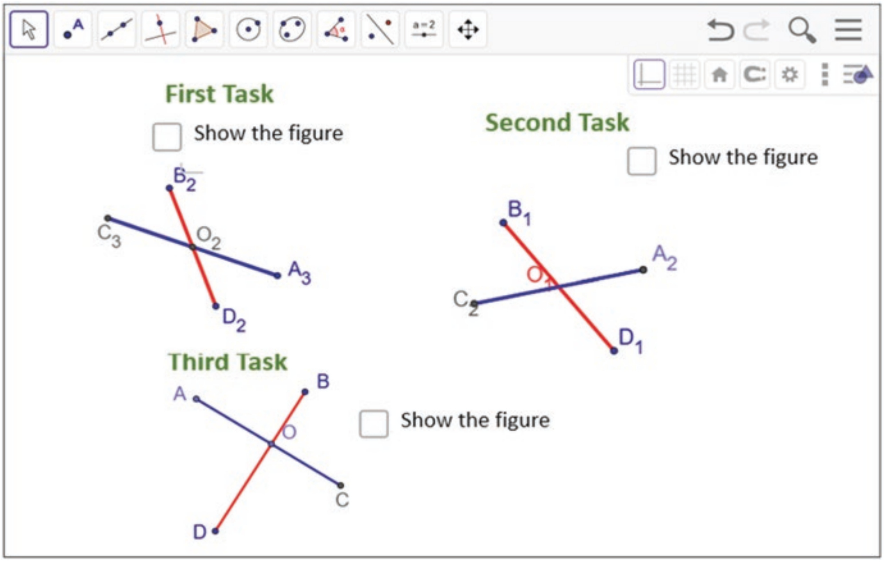


Fig. 5 Students' screen shot

6. Teacher Please, focus your attention on the first task only. Don't drag the other diagonals of the second and the third tasks.
7. Rafi But what is the question?
8. Rafi [*Rafi dragged point D in the figure of task 3 and point D1 in the figure of task 2*]
9. Shmuel Do you want to do the third task before doing the first and the second?
10. Rafi *Dragged several points while moving among the tasks*
11. Rafi What is the question?????????????????
12. Shmuel It is written on the worksheet we got
13. Yosef Look at your worksheet
14. Rafi I read but please tell me what is the question
15. Rafi [*Rafi continues dragging several points while moving among the tasks]*
16. Teacher Show the quadrilateral of the first task by pressing the checkbox and look at the instruction on the worksheet

The teacher observed that students were interacting randomly with the three figures (see Fig. 4) on the screen. In [6] she intervened to monitor the students work. She asked the students to focus on the first task among the three. It seems that Rafi, who was typing while the teacher typed, missed her request. For this reason, he asked his peers about the task's requirements [7]. Rafi demonstrated confusion as he dragged several points of all the figures [8]. It seems that Rafi's actions, on the shared Figures, confused Shmuel. Shmuel noticed the teacher's request and he asked Rafi ironically whether he intends to solve the second/third task or the first one. Shmuel [12] and Yosef [13] indicate that both were aware of the teacher’s request. They wanted to draw Rafi’s attention to the fact that they should focus on the first task but not on the others. At this moment, it seems that Rafi was still confused and did not understand the task requirements. The teacher observed this misunderstanding and instructed, “Show the quadrilateral of the first task by pressing the checkbox and look at the instruction on the worksheet”. This second intervention is a different type of monitoring. While in her first monitoring she gave a general remark, in the second, her suggestion was particular. She suggested a strategy that may help students to understand the task.

6.3 Asking for Justification

SAGLET provided an alert about a correct solution. The teacher received this alert and entered the virtual room and noticed that the student mentioned the final solution without desired justification. She asked them to justify their claim. This episode illustrates how the students react to the teacher request.

17 Teacher Why is the quadrilateral, a parallelogram? Please explain.
18 Yosef Because the diagonals bisect each other.
19 Rafi Because when we drag the figure, the opposite sides are always congruent.
20 Shmuel I agree.
21 Yosef Because it has two pairs of opposite equal sides.
22 Rafi And the opposite angles are also equals.

After the students typed their solutions without mentioning the reasons for them, the teacher decided to intervene [17]. As a result, all the students provided reasons to justify their answer. To justify his claim, Yosef focused on one aspect of the quadrilateral – the diagonals’ properties [18]. To support Yosef’s statement, Rafi provided a complementary explanation regarding the quadrilateral’s sides [19]. Finally, Rafi gave another reason regarding the angles of the quadrilateral [22]. The students’ utterances suggest that they were engaged in productive argumentation processes, namely, the students supported each other, and built on each other’s ideas; in this way they constructed acceptable justifications to their claim.

6.4 Scaffolding Learning Processes

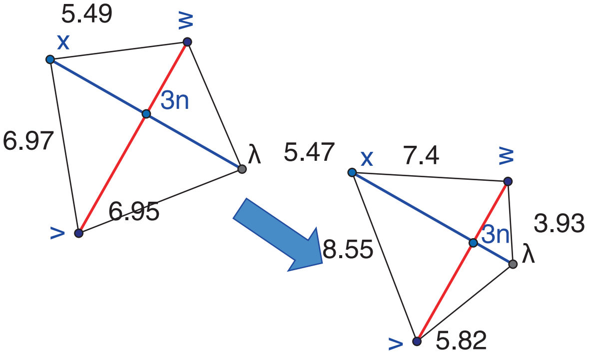
The teacher recognized that the students are confused while they continue dragging the segments presented in the first task without getting any idea about the quadrilateral’s type. She hinted the students how to display the quadrilateral’s sides. The following episode shows an intervention in which the teacher scaffolded and monitored the students' inquiry processes.

23 Teacher Mark the checkbox to display the quadrilateral sides.
24 Yosef Release the control please
25 Rafi [*Rafi marked the checkbox, as a result, the quadrilateral sides were displayed on the screen*]
26 Yosef Perfect! It is a parallelogram.
27 Rafi Parallelogram.
28 Yosef Just a moment! It is a square.
29 Teacher You should reach an agreement about the mutual solution.
30 Shmuel I think it is a kite.
31 Rafi [*Drags the quadrilateral]* it is a square.
32 Yosef All sides are congruent. So it seems like a square and not a kite.
33 Shmuel I agree.
34 Yosef Great.
35 Rafi You are both right. In addition, the angles are equal, so it is a square but not a rhombus or kite.
36 Yosef So the final answer is a square.

In this episode, the teacher intervened twice. In her first intervention, she requested the students to display the sides of the quadrilateral. This intervention plays the role of monitoring and scaffolding. Following her request, the students started inquiry processes to deal with the task, which was a bit unclear to them before the teacher intervened, and led to different (erroneous) conclusions about the type of quadrilateral. It seems that these different conclusions summoned the second intervention of the teacher, who wrote, "You should reach an **agreement** about the mutual solution." Asking the students to reach an agreement triggered them to rise hypotheses and to give reasons for them. In other words, the teacher's intervention afforded argumentative dialogue. Shmuel argued that the quadrilateral is a kite and Yosef challenged him and typed: "All sides are congruent. So it seems like a square, but not a kite." Shmuel was convinced. Furthermore, Rafi added an argument to support the claim by typing: "You are both right. In addition, the angles are equal so it is a square but not a rhombus or kite." [35]

The following episode presents the second type of teacher's scaffolding learning processes intervention. This type is characterized by the teacher's controlling of the dynamic tool. This type is different from the first type, for which the teacher typed statements in the chat box.

37	Teacher	Please, release the control.
38	Teacher	[*She drags Fig. C and produces a quadrilateral which is not a square*]



39	Teacher	Is it a square now?
40	Yosef	No.
41	Rafi	No.
42	Teacher	So, what do you see?
43	Yosef	A kite.
44	Teacher	Why do you think it is a kite? Do you see a kite?
45	Rafi	How is it a kite?
46	Teacher	If not a kite? What kind of quadrilateral is preserved under all your dragging inquiries?
47	Rafi	Just a quadrilateral with no special name.

The teacher noticed that the students in the room had difficulties in identifying the actual answer to the challenging task. Indeed, the fact that the solution of the task is a no-name quadrilateral, presents a challenge for students. It seems that using the chat box alone without producing a counterexample was not sufficient to scaffold students' inquiry. By doing so with the dynamic tool, she produced a counterexample for the students' hypothesis. This action afforded the students to reach the right answer of this challenging task (Task 3).

6.5 Social Validation

The teacher used the social validation mainly after the students achieved a correct answer on which she got an alert, or provided a full justification for their claims. In this episode, we illustrate how a social validation was reflected in the student's work going further.

48	Teacher	You are great! Well done.
49	Gilad	May I have the control?
50	Itamar	Take it.
51	Gilad	[Drags points D1, B1, A2, C2 in the figure of the second task for about 15 s].

These utterances are taken from the protocols right after the group found the correct solution for the first task. The students provided a full justification for their solution. Up to this moment, Gilad, a member of the group, collaborated with his peers by typing in the chat box without using the dynamic tool by himself. After the social validation of the teacher [48], Gilad got the courage to asked for the first time for the control of the DGE tool.

7 Discussion and Conclusions

In this chapter, we presented examples of interventions by the teacher that were followed by episodes in which students seemed to have learning gains from these interventions. For example, we showed that the teacher's scaffolding of the student engagement in inquiry processes such as questioning, hypothesizing, and verifying/refuting hypotheses, was effective, as we showed the immediate impact of the teacher's interventions on further interactions. For each of the examples shown, one may ask about the novelty of this teaching-learning practice. Many researchers have shown that teachers' actions may be effective in group learning (e.g., Webb, 2009). However, the interactions here were deployed in a context of orchestration. We found that the teacher was aware of critical moments in the students' learning processes monitoring several groups simultaneously, being provided by alerts on time. This is a novel and very important finding. Yet, we did not check this impact in further activities though. For example, we did not ask students to participate in aftermath individual tests. One may then question the scope of our examples in two senses. First, these are only examples and they may not be representative. Second, we did not fully tackle the issue of the beneficial effects of the interventions after interactions at an individual level. Our approach about the sending of alerts, however, was based on previous empirical findings: For example, the importance of social validation of the correctness of solution for learning gains has been already documented (Monteil, 1989). Asterhan and Schwarz (2016) demonstrated the beneficial effect of challenges and explanations on conceptual learning. These studies suggest that prolonged moments of idleness, non-validated achievements, off-task engagement, and deliberative argumentation are critical moments in social interaction. The fact that the teacher boosted or remediated during these critical moments indicates that her interventions went in the right direction of conceptual learning.

We cannot respond to the question of the representativeness of our study but the examples we presented show quite clearly instances in which students after going astray from the task proposed, and being confused, were put on the right track of the achievement of the tasks. In addition, Schwarz et al. (2018) showed that most of the groups reached the right solutions with right explanations for most of the tasks. The examples we provided show then that the a priori very difficult activity of orchestration in which the teacher jumps from one group to the other to help in conceptual learning, was achieved well, in the sense that the interventions of the teacher were followed by responsive actions of the students.

The examples we provided indicate other interesting phenomena. First, as the teacher monitored group progression, she often realized that the students did not understand the question at stake. SAGLET allowed the teacher to be aware of the students' actions and confusion. After dissipating misunderstanding and confusion, the teacher could monitor learning processes in a more focused way.

The design of the environment and of the system of alerts helped the teacher in intervening when the intervention was relevant to the needs of the students. The examples we presented showed this fact clearly. As mentioned above, this relevance is critical for the effectiveness of guidance in discussions (Webb, 2009). It is remarkable then that the teacher could attend multiple discussions on-line and intervene (with the help of alerts) in a relevant way. This study indicates then that orchestration of multiple groups with the help of dedicated technologies is a promising direction towards the elaboration of new and sophisticated teaching practices.

References

Arzarello, F., Olivero, F., Paola, D., & Robutti, O. (2008). The transition to formal proof in geometry. In P. Boero (Ed.), *Theorems in schools: From history, epistemology and cognition to classroom practices* (pp. 307–324). Rotterdam, The Netherlands: Sense Publishers.

Asterhan, C. S. C., & Schwarz, B. B. (2016). Argumentation for learning: Well-trodden paths and unexplored territories. *Educational Psychologist, 51*(2), 164–187.

Baker, M. (2003). Computer-mediated argumentative interactions for the co-elaboration of scientific notions. In J. Andriessen, M. Baker, & D. Suthers (Eds.), *Arguing to learn, confronting cognitions in computer-supported collaborative learning environments* (pp. 47–70). Utrecht, The Netherlands: Kluwer Academic Publishers.

Boero, P. (2008). Theorems in school: An introduction. In P. Boero (Ed.), *Theorems in schools: From history, epistemology and cognition to classroom practices* (pp. 19–24). Rotterdam, The Netherlands: Sense Publishers.

Crouch, C., & Mazur, E. (2001). Peer instruction: Ten years of experience and results. *American Journal of Physics, 69*, 970–977.

De Villiers, M. (1994). The role and function of a hierarchical classification of quadrilaterals. *For the Learning of Mathematics, 14*(1), 11–18.

De Villiers, M. (2010). Experimentation and proof in mathematics. In G. Hanna, H. N. Jahnke, & H. Pulte (Eds.), *Explanation and proof in mathematics* (pp. 205–221). Boston, MA: Springer.

Dillenbourg, P. (2013). Design for classroom frchestration. *Computers & Education, 69*, 485–492.

Drijvers, P., Doorman, M., Boon, P., Reed, H., & Gravemeijer, K. (2010). The teacher and the tool: Instrumental orchestrations in the technology-rich mathematics classroom. *Educational Studies in Mathematics, 75*(2), 213–234.

Erez, M., & Yerushalmy, M. (2006). If you can turn a rectangle into a square, you can turn a square into a rectangle: Young students' experience the dragging tool. *The International Journal of Computers for Mathematical Learning, 11*(3), 271–299.

Fujita, T., & Jones, K. (2007). Learners' understanding of the definitions and hierarchical classification of quadrilaterals: Towards a theoretical framing. *Research in Mathematics Education, 9*(1&2), 3–20.

Hadas, N., Hershkowitz, R., & Schwarz, B. B. (2001). The role of surprise and uncertainty in promoting the need to prove in computerized environment. *Educational Studies in Mathematics, 44*(1&2), 127–150.

Hanna, G. (1990). Some pedagogical aspects of proof. *Interchange, 21*(1), 6–13.

Hershkowitz, R. (1990). Psychological aspects of learning geometry. In P. Nesher & J. Kilpatrick (Eds.), *Mathematics and cognition* (pp. 70–95). Cambridge, UK: Cambridge University Press.

Hsieh, H.-F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research, 15* (9), 1277–1288.

Jones, K. (2000). Providing a foundation for deductive reasoning: Students' interpretations when using dynamic geometry software and their evolving mathematical explanations. *Educational Studies in Mathematics, 44*, 55–85.

Kazemi, E. (1998). Discourse that promotes conceptual understanding. *Teaching Children Mathematics, 4*(7), 410–414.

Lakatos, I. (1976). *Proofs and refutations*. Cambridge, UK: Cambridge University Press.

McCrone, S. (2005). The development of mathematical discussions: An investigation of a fifth -grade classroom. *Mathematical Thinking and Learning, 7*(2), 111–133.

Monteil, J.-M. (1989). *Eduquer et former*. Grenoble, France: Presses Universitaires de Grenoble.

Ng, O., & Sinclair, N. (2015). "Area without numbers": using touch- screen dynamic geometry to reason about shape. *Canadian Journal of Science, Mathematics and Technology Education, 15*(1), 84–101.

Prusak, N., Hershkowitz, R., & Schwarz, B. B. (2012). From visual reasoning to logical necessity through argumentative design. *Educational Studies in Mathematics, 79*(1), 19–40.

Roschelle, J., & Teasley, S. D. (1995). The construction of shared knowledge in collaborative problem solving. In C. O'Malley (Ed.), *Computer supported collaborative learning* (Vol. 128, pp. 69–97). Berlin, Germany/Heidelberg, Germany: Springer.

Rummel, N., & Spada, H. (2005). Learning to collaborate: An instructional approach to promoting collaborative problem solving in computer-mediated settings. *Journal of the Learning Sciences, 14*(2), 201–241.

Schwarz, B. B., Prusak, N., Swidan, O., Livny, A., & Gal, K. (2018). Orchestrating deep learning: A case study in a geometry class. *International Journal of Computer Supported Collaborative Learning, 13*(2), 189–211.

Sinclair, N., & Robutti, O. (2013). Technology and the role of proof: The case of dynamic geometry. In A. Bishop, K. Clement, C. Keitel, J. Kilpatrick, & F. Leung (Eds.), *Third international handbook of mathematics education* (pp. 571–596). Berlin, Germany: Springer.

Stahl, G. (2009). *Studying virtual math team*. London, UK: Springer.

Van Hiele, P. M. (1986). *Structure and insight: A theory of mathematics education*. Orlando, FI: Academic.

Webb, N. M. (1991). Task-related verbal interaction and mathematics learning in small groups. *Journal for Research in Mathematics Education, 22*(5), 366–389.

Webb, N. M. (1995). Group collaboration in assessment: Multiple objectives, processes, and outcomes. *Educational Evaluation and Policy Analysis, 17*(2), 239–261.

Webb, N. M. (2009). The teacher's role in promoting collaborative dialogue in the classroom. *British Journal of Educational Psychology, 79*, 1–28. https://doi.org/10.1348/000709908X380772

Naomi Prusak works at Hebrew University, Jerusalem; David Yellin College of education, Jerusalem, where she completed her PhD, with specialization in the second and third degree: science education. Her research interests are in Mathematics Education. In particular, she studies the cognitive aspects of mathematics learning, geometrical reasoning and proof, argumentation in a problem-solving context, and the use of computers in mathematics education.

Her experiences as an instructor of teacher training courses, and a curriculum developer and designer and the findings from her researches have cultivated her beliefs about the ways concepts and ideas should be taught, as well as the ways students might learn them meaningfully and effectively.

Osama Swidan is a mathematics education researcher at Ben-Gurion University of the Negev. He completed his Ph.D. degree in 2015 and did his first post-doctoral research in the Hebrew University of Jerusalem and his second post-doctoral, he did in 2017 in Turin University. Osama's research area covers learning and teaching mathematics with digital tools. Particularly, he is interested in studying cognitive and emotional aspects through learning mathematical concepts. He won several prestigious scholarships, such Mandel Institute scholarship for outstanding doctoral students in education, the scholarship of the Planning and Budget Committee for Higher Education in Israel for three years, and recently, he was granted the prestigious scholarship "MAOF" for outstanding young researchers.

Baruch Schwarz is a full professor at the Hebrew University of Jerusalem. He began his career as a mathematician at the École normale supérieure in Paris. He then specialized in the Learning sciences. His research interests range from collaborative learning, the relations between social interactions and cognitive development, and in particular argumentation for learning, CSCL, and learning in Yeshivas. Baruch Schwarz has written numerous books and articles and has been a visiting professor in several universities such as Paris, Oslo and Neuchâtel.

Discussion: Creating a New World – Teachers' Work in Innovative Educational Environments

Yifat Ben-David Kolikant

1 Introduction

In this essay I discuss two chapters in this volume: (1) *Issues of teaching in a new technology-rich environment: Investigating the case of New Brunswick (Canada) school makerspaces*, by Viktor Freiman, and (2) *The influence of teacher's orchestration through the SAGLET system on students' conceptual learning—the case of a geometry lesson*, by Prusak, Swidan, and Schwarz.

The chapters share important characteristics. Both chapters describe teachers' work in innovative educational environments, aiming at, as Freiman puts it, "provid[ing] non-traditional learning opportunities for the students" (ibid.). Traditional schooling is characterized by information-focused agenda and teacher-centered practices (Fraillon, Ainley, Schulz, Friedman, & Gebhardt, 2014). Compared to those, both novel environments (a) are student-centered, (b) aim at nurturing twenty-first century skills, such as problem solving, creativity, sharing, and collaboration (Nir et al., 2016; OECD, 2018; Pellegrino & Hilton, 2012) and (c) are technology rich. Freiman's chapter revolves around makerspace environments in which students can design, experiment, build and invent while learning about STEAM (science, technology, engineering, arts, and mathematics). Students engage in a multitude of projects, during which they explore various technologies, create new things of all kinds, and share their products/designs with others. Prusak, Swidan, and Schwarz describe an educational environment in which students collaboratively solve problems in Geometry using a Dynamic Geometry Environment, GeoGebra, that allows them to 'drag' on-screen objects and produce a variety of diagrams, what can help them to examine conjectures and visualize proofs.

In this chapter I elaborate on the crosscutting themes in these chapters. First, I discuss the fruitful relationship between research and practice that both projects

---

Y. Ben-David Kolikant (✉)
Seymour Fox School of Education, Hebrew University of Jerusalem, Jerusalem, Israel
e-mail: yifat.kolikant@mail.huji.ac.il

Y. Ben-David Kolikant et al. (eds.), *STEM Teachers and Teaching in the Digital Era*, https://doi.org/10.1007/978-3-030-29396-3_17

demonstrate. Then I discuss the innovative nature of the pedagogies described in these chapters. I elaborate on the important role technology plays in facilitating transformative change, in sustaining a different classroom learning culture. Then I discuss the new roles of the teachers as portrayed in these chapters, especially what it means to have “teachers as guides,” and what knowledge and dispositions are involved when teachers aim at maximizing their students’ learning.

2 A Fruitful, Reciprocal Relationship Between Research and Practice

In each of the chapters the described educational environments are inspired by research and theory. The makerspace is grounded in the constructionist philosophy (Harel & Papert, 1991). The environment described by Prusak, Swidan, and Schwarz is grounded in the field of computer-supported collaborative learning (CSCL) (e.g., Roschelle & Teasley, 1995) and argumentation (Baker, 2003). Furthermore, the SAGLET software, that the teachers use, is an outcome of a collaborative research effort of educational researchers and computer scientists (Schwarz, Prusak, Swidan, Livny, & Gal, 2018).

The relationship between research and practice is reciprocal as both chapters shed light on an important topic: teachers’ functioning in such innovative, student-centered environment and their professional growth. What roles do they assume? What practices, knowledge, and dispositions are developed in that process? And, what impact do these teachers have on students’ learning? In both environments, the teachers have to learn to guide the students who often work within multiple tasks, what adds to the complexity of the milieu. This new reality requires teachers to develop different instructional practices in order to maximize students’ learning. The teachers in the study by Prusak, Swidan, and Schwarz use SAGLET, to monitor and orchestrate multiple student groups engaged in parallel on a learning task. The software recognizes critical moments within the groups that are interacting and present this information to the teacher visually. Yet, it is the teacher’s decision as to how to interfere productively in the group work, if at all. The teachers in the study by Freiman needed to support multiple students who work on their own, different projects, often encountering situations when they lack the knowledge required for a specific project.

3 Technology as a Facilitator of Innovative Educational Environment

Each of the two chapters demonstrates the important role of technology in transforming students’ learning and its potential to transform the school/classroom learning culture. The environments in both chapters aim at forming what Salomon, Perkins, and Globerson (1991) termed 'a productive human-computer intellectual partnership.' Salomon et al. distinguished between two types of positive effects of technology on human intellectual performance: effect *with* technology, which refers to changes in the performance of students while equipped with a technology (i.e., a program or a tool), for example, the reduced number of spelling mistakes while using a word processor; and the effect *of* technology, which refers to relatively long-lasting residue in students' abilities and dispositions as a result of interaction with a technology, evident even when they are away from it. Both environments build on the effects *with* and *of* technology, in terms of capitalizing on the experience of today's students with technology and the thinking it encourages (Ben-David Kolikant, 2019); both aim at transforming this human-technology interaction to yield productive learning.

Tools are mediational means, namely when we are introduced to a new tool, our sense of its affordances and constraints gradually evolves, and our goals and actions with the tool, as well as our understanding of the context within which we act, are transformed (Wertsch, 1998). This conceptualization suggests that ICTs transforms students and other users' actions and values, namely, what is deemed as good, appropriate, and efficient in this respect (Bolter, 1984; Brown, 2000; Wertsch, 1998).

Specifically, both environments are aimed at encouraging bricolage or tinkering, which can be taken to mean 'trial-and-error,' learning by "poking around, doing this or that and eventually get it right " (Papert, 1996, p. 86). Bricolage is also about "the abilities to find something – an object, tool, document, a piece of code – and to use it to build something you deem important" (Brown, 2000, p. 14). Turkle asserts that computer and Internet technology made bricolage legitimate or even necessary skill. Computer use moves us "in the direction of accepting the postmodern values of opacity, playful experimentation, and navigation of surface as privileged ways of knowing" (Turkle, 1995, p. 267). Similarly, Brown (2000) claims that life with the Internet brought about a shift in what is considered as valid reasoning, from the linear, deductive, abstract style of the book generation, to bricolage.

Both environments build on this capacity of the technology. Prusak, Swidan, and Schwarz believe that "teaching geometry should encourage the adoption of experimental learning methods and implementation of inquiry techniques… an activity that invites the use of **intuition, visualization,** and **trial and error** modes of investigation" (ibid., p. 293 emphasis in original). The dynamic visualization of the DGE [Dynamic Geometry Environments] invites such learning methods. Similar ideas are expressed by Freiman who envisions: "an environment in which students can design, experiment, build and invent while learning about STEAM" (ibid., p. 273).

Modern Information and Communication Technology (ICT) also encourages sharing and collaboration (Bonk, 2009). For example, Bruns (2007) points out the emergence of what he termed 'produsaging' – a new hybrid form of simultaneous production and usage – amidst today's generations of users. The ICT users are thus engaged in collaborative and continuous building and extending of existing content in pursuit of further improvement (e.g., Wikipedia). In both environments students are expected to collaborate and share, to test their ideas in light of critiques and alternative ideas provided by their peers.

Finally, the SAGLET technology described by Prusak, Swidan, and Schwarz is but one example of a fruitful human-computer partnership that enables cognitive efforts otherwise almost impossible. In Prusak et al.'s case it enabled the teachers to guide multiple groups of students who worked on learning tasks. It is as if the teacher and the computer co-participated in all groups' discussions simultaneously—the computer identified situations that require intervention and the teacher decided how to interfere, if at all.

Obviously, not all the interactions with technology are productive (Ben-David Kolikant, 2012; Selwyn, 2017), and obviously, not all collaborative learning situations are productive (see, for example, Barron, 2003). Our actions (with tools) result from dealing with multiple, often-conflicting goals, some of which are associated with our experience with the tool and the context of its use (as well as our history in general), some with power and authority, (for example, when students' are asked by the teachers to solve a calculation exercise without using a calculator, and using a calculator means cheating), and some with a combination of these factors (Wertsch, 1998). Students can be dragged into endless "hands-on minds-off" trial and error, whereas educators aspire for a growth in students' conceptual understanding as well as the development of learning skills and knowledge. This is when the teacher's guidance becomes an important asset.

4 Teachers as Guides and Facilitators

Teaching is about maximizing students' learning. Teachers have a unique knowledge, termed by Shulman (1986, 1987) pedagogical content knowledge (PCK), that enable them to maximize their students' learning. In traditional schooling, characterized by information-focused agenda and teacher-centered practices, the pursuit of PCK revolves around the question as to how to best explain to students a certain piece of knowledge (Resnick, 2002). This is evident, for example, in Shulman's explanation that PCK includes "the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word, the ways of representing and formulating the subject that make it comprehensible to others." (Shulman, 1986, p. 9).

The environments described in the two chapters are student-centered. In both, teachers' roles had to shift, using the words of Prusak, Swidan, and Schwarz, "from lecturing and telling, to listening, observing, facilitating, and guiding" (ibid. p. 293). Teachers in such environment need to pursue different ways to maximize their students' learning. What characterizes their unique knowledge? The two chapters shed light on this timely issue.

First, teaching in these environments involves multi-tasking. Furthermore, these environments are characterized by great diversity—the teachers in both studies orchestrate multiple groups of students who sometimes work on different tasks, at different pace, encountering various social, cognitive, and metacognitive difficulties. In order to best support their students, the teachers have to adopt flexible (or resilient) approach towards the curriculum, let alone a personalized approach to it, which adds to the diversity that the multi-tasking teachers need to handle. Expert teachers have always been characterized by flexibility and the ability to recognize learning opportunities (Berliner, 2001, 2004; Tsui, 2009), however these novel environments require these characteristics amidst multiple personalized curricula.

Second, as prominent in the makerspace environments, these educational situations often involve the need to pursue new knowledge that the teachers did not master. In fact, learner-centered environments often require an interdisciplinary approach to the problem or task at hand. Teachers need to remain confident in such situations, to learn to live at peace with the fragility of their own knowledge and work productively even if required knowledge is distributed—between themselves, their students, and the environment (see also Kapon's discussion in this volume), and to guide students effectively in such situations. The distributed nature of knowledge is also evident in the work of teachers in SAGLET study. SAGLET, as well as other (artificial-intelligence based) systems, are aimed at distributing the cognitive load between the technology and the users. In the case of SAGLET, the orchestration is distributed between the teacher and the technology. Yet, this requires the teachers to adjust to this new context and capitalize on it; for maximizing students' learning, for example, they need to learn how to best intervene in the conversation where their presence so far was invisible to the students.

Third, the teachers have to generate and sustain a learning culture different from that of the traditional schooling. Freiman noticed that all the teachers he observed and interviewed have developed, as a result of their experience, an 'innovator's mindset'; that they focus on how "to empower learning, unleash talent and foster culture of creativity" (ibid., p. 273). While both environments capitalize on the bricolage that interaction with technology encourages, in both chapters the authors are aware of the various pitfalls, such as the tendency to be engaged in a "minds-off, hand-on" activity, and being satisfied when getting things to "work" (Ben-David Kolikant, 2011). Such concern is raised by Prusak, Swidan, and Schwarz, who aim at assisting the teacher in leading "shifts in the discourse, ensuring that it is conceptually focused and reflective" (p. 293). Freiman quotes Gilbert to express a similar concern: "the real educational value, in terms of productivity, consists in producing ideas: "expressing them, playing with them, testing them, trying them out in different combinations" (Gilbert, 2017, p. 94)" (ibid., p. 273). Groups also often fail due to fruitless interactions between members (e.g., Barron, 2003).

In both chapters, pursuing ways to maximize students' leaning take the form of sustaining productive collaborative learning culture. Freiman reports that the teachers he observed aim at "establishing a supportive, encouraging, caring, and risk-free learning environment for all students. Their approach is essentially inclusive, while targeting each student's higher potential" (ibid. p. 273). These teachers knew their students, in order not only to maximize each student learning, but also to build a collaborative culture where "students not only work together but also help each other based on everyone's unique forces" (ibid.). Thus, these teachers viewed their students as potential resources for their peers and themselves, as designers of fruitful social interaction between the students.

In conclusion, the knowledge teachers have to develop involves the ability to multi-task, to address diversity, and to utilize diversity of learning resources, the ability to support students in situations in which the knowledge required is distributed among the teachers, the students, and the technology. This knowledge for the twenty-first century teaching involves design of social interaction and the implementation of social practices in order to sustain a culture of fruitful collaboration and creative knowledge creation.

The notion of PCK was coined at time when content knowledge was rather stable and teachers were assumed to master it. Teachers' growing experience was expected to contribute to their PCK, their ability to make certain pieces of knowledge comprehensible to the students (Liberman, Ben-David Kolikant, & Beeri, 2012). As schools adjust to the twenty-first century demands, learning environments such as described in these two chapters—student-centered, collaborative, and focused on knowledge creation—will become prevalent. Knowledge in these environment is no longer stable. It is dynamic and moreover, it is distributed between the various elements and actors within the environment: teachers, students, and tools. Teachers' PCK can and should support their abilities to maximize learning in such environments. For example, Freiman's teachers used their PCK to identify the strengths of their students and to design the social interaction so that the students will serve as resources for the group. However, the nature of PCK expands in order to support teachers' new roles. For example, teachers were always expected to be flexible and adaptive, but the multi-tasking, the diversity inherent in these environments, and the need to effectively guide students amidst distributed, often cross-disciplinary (content) knowledge, paint flexibility and adaptiveness in new colours. Finally, the relation between teachers' PCK and the content knowledge requires further examinations confronted with the reality of distributed knowledge.

References

Baker, M. (2003). Computer-mediated argumentative interactions for the co-elaboration of scientific notions. In J. Andriessen, M. Baker, & D. Suthers (Eds.), *Arguing to learn, confronting cognitions in computer-supported collaborative learning environments* (pp. 47–70). Utrecht, The Netherlands: Kluwer Academic Publishers.

Barron, B. (2003). When smart groups fail. *The Journal of the Learning Sciences, 12*(3), 307–359.

Ben-David Kolikant, Y. (2011). Computer science education as a cultural encounter: A socio-cultural framework for articulating teaching difficulties. *Instructional Science, 39*(4), 543–559.

Ben-David Kolikant, Y. (2012). Using ICT for school purposes: Is there a student-school disconnect? *Computers & Education, 59*(3), 907–914.

Ben-David Kolikant, Y. (2019). Adapting school to the twenty-first century: Educators' perspectives. *Technology, Pedagogy and Education, 28*(3), 287–299.

Berliner, D. C. (2001). Learning about and learning from expert teachers. *International Journal of Educational Research, 35*(5), 463–482.

Berliner, D. C. (2004). Describing the behavior and documenting the accomplishments of expert teachers. *Bulletin of Science, Technology & Society, 24*(3), 200–212.

Bolter, J. D. (1984). *Turing's man: Western culture in the computer age*. Chapel Hill, NC: University of North Carolina.

Bonk, C. J. (2009). *The world is open: How web technology is revolutionizing education*. New York, NY: Wiley.

Brown, J. S. (2000). Growing up: Digital: How the web changes work, education, and the ways people learn. *Change: The Magazine of Higher Learning, 32*(2), 11–20.

Bruns, A. (2007). Produsage: Towards a broader framework for user-led content creation. In *Creativity and cognition: Proceedings of the 6th ACM SIGCHI conference on creativity & cognition* (pp. 13–15). ACM.

Freiman, V. (2019). Issues of teaching in a new technology-rich environment: Investigating the case of New Brunswick (Canada) school makerspaces. In Y. B.-D Kolikant, D. Martinovic, & M. Milner-Bolotin, (Eds.), *STEM teachers and teaching in the digital era* (pp. 273–292). Cham: Springer.

Fraillon, J., Ainley, J., Schulz, W., Friedman, T., & Gebhardt, E. (2014). *Preparing for life in a digital age.* The IEA international computer and information literacy study international report. Australia. Retrieved from https://link.springer.com/content/pdf/10.1007/978-3-319-14222-7.pdf

Gilbert, J. (2017). Educational makerspaces: Disruptive, educative or neither? *New Zealand Journal of Teachers' Work, 14*(2), 80–98.

Harel, I. E., & Papert, S. E. (1991). *Constructionism*. New York, NY: Ablex Publishing.

Liberman, N., Kolikant, Y. B. D., & Beeri, C. (2012). "Regressed experts" as a new state in teachers' professional development: Lessons from computer science teachers' adjustments to substantial changes in the curriculum. *Computer Science Education, 22*(3), 257–283.

Nir, A., Ben-David, A., Ben-David, A., Bogler, R., Bogler, R., & Zohar, A. (2016). School autonomy and 21st century skills in the Israeli educational system: Discrepancies between the declarative and operational levels. *International Journal of Educational Management, 30*(7), 1231–1246.

OECD. (2018). *Organisation for economic co-operation and development*. Directorate for Education and Skills. The future of education and skills: Education 2030. Partnership for 21CS.

Papert, S. (1996). *The connected family: Building the digital generation gap*. Atlanta, GA: Longstreet.

Pellegrino, J. W., & Hilton, M. L. (2012*). Education for life and work: Developing transferable knowledge and skills in the 21st century*. National Research Council. Washington, DC: The National Academies Press.

Prusak, N., Swidan, O., & Shcwartz, B. (2019). The influence of teacher's orchestration through the SAGLET system on students' conceptual learning—The case of a geometry lesson. In Y. B.-D Kolikant, D. Martinovic, & M. Milner-Bolotin, (Eds.), *STEM teachers and teaching in the digital era* (pp. 293–311). Cham: Springer.

Resnick, M. (2002). Rethinking learning in the digital age. In G. Kirkman (Ed.), *The global information technology report: Readiness for the networked world* (pp. 32–27). New York, NY: Oxford University Press.

Roschelle, J., & Teasley, S. D. (1995). The construction of shared knowledge in collaborative problem solving. In C. O'Malley (Ed.), *Computer supported collaborative learning* (Vol. 128, pp. 69–97). Berlin, Germany/Heidelberg, Germany: Springer.

Salomon, G., Perkins, D. N., & Globerson, T. (1991). Partners in cognition: Extending human intelligence with intelligent technologies. *Educational Researcher, 20*(3), 2–9.

Schwarz, B. B., Prusak, N., Swidan, O., Livny, A., & Gal, K. (2018). Orchestrating deep learning: A case study in a geometry class. *International Journal of Computer Supported Collaborative Learning, 13*(2), 189–211.

Selwyn, N. (2017). Digital inclusion: Can we transform education through technology? En P. Rivera-Vargas, E. Sánchez, & R. Morales (coords.), *Conocimiento para la equidad social: pensando Chile globalmente* (pp. 103–108). Santiago de Chile, Chile: Colección Políticas Públicas – USACH.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1–22.

Tsui, A. B. M. (2009). Distinctive qualities of expert teachers. *Teachers and Teaching: Theory and Practice, 15*(4), 421–439.

Turkle, S. (1995). *Life on the screen: Identity in the age of the internet*. New York: Simon & Schuster.

Wertsch, J. (1998). *Mind as action*. New York, NY: Oxford University Press.

Yifat Ben-David Kolikant is an Associate Professor in the Seymor Fox School of Education, Hebrew University of Jerusalem. Her academic work is devoted to theorizing learning, teaching, and schooling in the age of globalization and digitalism, an age characterized by the ubiquity of digital technology, an information explosion, pluralism, and rapid changes. Over the past few years, she has dealt with two core questions: (a) How does digital technology influence schooling and (b) how can effective teaching environments be characterized? In recent years she has been involved in several studies aimed at understanding and enhancing in-service teacher learning under conditions of dramatic curricular and policy changes, and the role that ICT plays and should play in it. Prof. Ben-David Kolikant holds a Ph.D. degree in science teaching from the Weizmann Institute of Science, received in 2002.

Index

A
Adult learning, 67, 79, 85, 160, 193
Affordances, 11, 59, 103, 160, 247, 257, 261, 264–266, 268, 277, 282, 284, 295, 315
Appropriating ICT for instruction, 261, 266, 267
Appropriation, 11, 266–268
Argumentation, 294–296, 305, 308, 314
A sense of belonging and identification, 118, 121, 122, 124, 130
A sense of presence, 122, 131

B
Body, vii, 2, 22, 92, 103, 104, 232
Boundaries, v, ix, x, 6, 53, 56, 65, 68, 69, 85, 94, 97, 117, 119, 130, 135, 154, 185, 250
Boundary objects, 97
Boundary-crossing processes, 65, 68, 69, 85

C
Canada, v, ix, x, 1, 20, 25, 53, 185, 187, 204, 212, 273–289, 313
Challenges in integrating ict into instruction, 222, 261, 275
Chemistry education, 112, 116, 118, 121, 127, 128, 133, 134, 186, 187, 192
Chemistry teachers' PLC, 112, 113, 115–117
Classroom practice, viii, 25, 95, 150, 154, 155, 160, 233
Cognitive functions, 263
Cognitive process, 244, 263, 265
Collaboration, vii, 2, 4, 6, 8, 10, 12, 20, 23, 24, 29–33, 37, 50, 54, 55, 66, 68, 85, 111–113, 168, 195, 205–208, 210–215, 227, 228, 230, 274, 276, 278, 280, 281, 286, 287, 293–295, 300, 302, 303, 313, 315, 318
Collaborative inquiry (CI), 23–25, 31, 54, 191
Collaborative learning, 19, 27, 32, 59, 73, 85, 135, 159, 164, 172, 174, 175, 179, 180, 187, 204, 265, 294, 295, 316, 317
Collaborative Learning Annotation System (CLAS), 207, 209–211, 215, 264
Collaborative technology enhanced pedagogy, 207, 215
Collaborative textbook editing, 38
Collective knowledge, 58
Collective teacher efficacy, 31, 54
Community facilitators (CFs), 116, 119
Complexity of institutional and historical practices, 55
Computer science, viii, x, 6, 10, 141–155, 185–188, 190, 191, 193, 194, 281
Computer supported collaborative learning (CSCL), 293, 295, 314
Concepts, vii, 5, 31, 50, 55, 79, 92, 126, 142, 159, 188, 206, 237, 244, 264, 280, 297, 316
Conceptual learning, 12, 293–309, 313
Connections between teachers and curriculum developers, 43, 47, 55
Connections between teachers and mathematicians, 46, 47
Connections between teachers and textbook authors, 8, 43–46, 49, 50, 55
Constraints of ICT, 264–266
Content knowledge (CK), 25, 29, 55, 57, 71, 73, 78, 84, 116, 143, 174, 175, 193, 222, 224, 233, 236, 318

Y. Ben-David Kolikant et al. (eds.), *STEM Teachers and Teaching in the Digital Era*, https://doi.org/10.1007/978-3-030-29396-3

Continuing professional development (CPD), 66, 67, 69, 70
Cross-disciplinary knowledge, 318
Culture of inquiry, 24, 26, 27
Culture of learning, 26, 54
Curricular change, 144, 155, 288

D
Decimal expansion of a fraction, 248, 249, 267
Deliberate Pedagogical Thinking with Technology (DPTwT), 10, 201–215, 261
Deliberate use of technology, 206–207
Dialogic, 57, 296
Differentiated professional development, vi, vii, ix–xi, 1, 2, 5–7, 9, 10, 12, 23–26, 43, 46, 50, 54, 55, 65–67, 69, 70, 77, 78, 84, 85, 112, 113, 116, 135, 136, 144, 145, 151, 155, 159–181, 185–196, 205, 232
Distributed cognition, 11, 262, 268
Distributed knowledge, 58, 317, 318
Diversity, 154, 228, 278, 286, 287, 316, 318
Division by zero, 245–247
Dragging, 92, 97, 254, 296, 297, 303–305, 307
Dynamic geometry, 254, 296, 313, 315
Dynamic geometry tools, 306–308
Dynamic knowledge, 318

E
Education systems, 2, 4, 19, 24, 32, 145, 190, 274–276
Education videos, 192, 202, 207, 212, 213
Educational reforms, 2, 23, 24, 174, 176, 192, 195, 203, 275–276
Educational technology, x, 10, 11, 19, 202–204, 207, 210, 212–214, 261–269
Educators-led inquiry projects, 20, 54
Empowering teachers, x, 6, 55
Era of change, vi, ix, 1–13, 19–33, 53, 59, 96, 185–196

F
Fermat Last Theorem, 245
Fibonacci numbers, 252, 255, 262
Fidelity, 11, 48, 50, 194, 244, 246, 248, 254, 256–258
Fingers, 100, 101, 103, 105
Forms of doing, 261–264
Forms of instruction and learning, 269
Fragile knowledge, 149, 154
Fulfillment of needs, 114, 132–134, 186
Future STEM teachers, 203

G
GeoGebra, 298, 299, 313
Geometry learning, 95, 293–309
Gestures, 104
Growth mindset, 211

I
Ice-water glass, 74, 75, 77
Implementations of ICT, 232, 233, 265
Influences, 20, 32, 37, 43, 47, 49, 55, 56, 58, 78, 79, 85, 93, 112–114, 122, 124–126, 130–132, 135, 136, 145, 165, 178, 186, 187, 204, 243, 276, 287, 293–309
Information and communication technology (ICT), x, 4, 11, 221–224, 226, 227, 230–234, 237–240, 261, 262, 264–268, 273–275, 277, 279, 287, 315
Innovative learning environment, 313–318
Innovative pedagogies, x, 204
Innovative teaching, 133, 176, 227, 276
Inquiry-based collaboration, 57
Instructional affordances, 261, 264–265, 268
Instrumental genesis, 95, 222–226, 228, 232, 234, 237, 238, 264, 265, 268
Instrumental orchestration, 293–309
Inter- and transdisciplinary competences, 274, 285, 288
Interconnected model of professional growth, 160–161, 187
Intrinsic affordances, 265, 266
Isolation, 6, 94
Israel, v, ix, 1, 9, 10, 53, 65, 66, 70, 71, 78–84, 112, 116, 133, 142, 145, 163, 187, 190, 222

J
Job-embedded professional learning, 25

K
Knowledge-as-practice, x, 10, 189–192, 194
Knowledge-for-practice, x, 10, 189–190
The Knowledge Integration perspective on learning, 81
Knowledge-of-practice, x, 10, 189, 192
K-12 teachers, 26, 287

L
Lead teachers, 10, 22, 23, 185–195
Learner-centered teaching, 81, 84, 124
Learning as actions and activities, 55
Learning culture, x, 314, 317
Learning environments, x, 12, 57, 58, 173, 178, 204, 206, 207, 212–215, 229, 231, 232, 283, 295, 298, 299, 303, 317, 318
Learning interactions, 59, 92
Learning leadership teams, 188

M
Makerspaces, 11, 273–289, 313
Materials, 8, 10, 19, 41, 47, 67, 74, 75, 83, 84, 96, 98, 104, 116, 118, 121, 142, 143, 146, 147, 151, 154, 155, 188, 192, 195, 213, 276, 279, 280
Mathematical fidelity, 11, 244, 246, 256–258
Mathematical knowledge for professional development, 193
Mathematics leadership community of practice, 8, 30, 54
Mathematics leadership learning projects (MLLP), 30–32, 191
Membership, 114, 117–124, 130–132, 186
Meta-PCK, 154–155
Metonymy, 103
Mindset, 12, 211, 282, 287, 317
Models of professional development, 25, 67
M-TET project, 37–39, 45, 47, 48
Multiple orchestration, 309
Multiple support, 30, 314
Multitouch, 92

O
Online communication platform, 112, 116
Online communities, 114, 115, 133, 135
Ontario Mathematics Knowledge Network, 30
Ontology, 94–100
Orchestration, 12, 227, 293–309, 313, 317
Ordinal, 100, 102, 103

P
Pedagogical content knowledge (PCK), 95, 142–145, 147, 148, 150, 152–155, 187, 194, 206, 208, 209, 243, 316, 318
Peer Instruction, 204, 207–214
Peer teaching, 141, 144–145
PeerWise, 207–215
Physics learning and teaching, 83, 84
Physics teaching, 80, 84
Polygon, 249–253, 265
Practical knowledge, 59, 143, 152, 191, 192, 205
Practices, vi, 1, 20, 40, 53, 65, 95, 111, 141, 159, 185, 202, 229, 266, 273, 293, 313
Practice-to-practical knowledge (PPK), 154
Practitioner research, 65, 67, 68, 85
Problem solving, vi, 7, 29, 210, 262, 274, 276, 281, 289, 296, 297, 313
Professional development (PD), 10, 27, 54, 159, 185
Professional discourse in communities of learning, 59
Professional knowledge, 6, 7, 11, 20, 33, 57, 59, 131, 144, 174, 175, 206, 229, 237, 261, 267, 268
Professional knowledge for teaching, 268
Professional learning communities (PLCs), x, 6, 9, 33, 65–85, 111–136, 159–181, 185
Professionalism, 6, 144

R
Reflective practitioners, 67
Reinforcement, 114, 117, 118, 125–129, 132–134, 186
Relation between knowledge types, 143
Research, vi, 1, 20, 37, 54, 66, 91, 111, 142, 159, 185, 202, 221, 243, 293, 313
Research-engaged school, 26, 54
Research-practice partnership (RPP), 65–69

S
Scaffolding, 294, 302, 305–308
Scholarship of teaching, 65, 68, 69, 85
School-based research, 24
School board-university partnership, 54
Science education, 65, 159, 185, 204
Science teaching, 71
Science, Technology, Engineering and Mathematics (STEM), v, 1, 65, 187, 202, 261, 273
Scripting, 246–249, 252
Script writing, 246–252
Sense of community (SoC), 9, 111–136, 185, 186, 189, 191
Shared emotional connection, 114, 128, 134, 186
Social network, 5, 135, 136, 186
Socio-cultural theories on learning, 69, 81

Soft-skills, 288
Standards for teachers, 230, 239
STEM education, vi, 2, 5–7, 66, 71, 73, 202–204, 207, 209, 212, 213, 276, 277, 289
STEM-education reform, 7, 187
STEM learning, 202, 203, 207, 211, 268, 269
STEM methods courses, 205, 206, 209–212, 214
STEM teaching, x, 10, 11, 71, 205, 261–269
Student-centered environments, 314
Student-centered pedagogies, 7
Student drawing of micro-macro, 74
Sum of exterior angles in a polygon, 249–253, 265
Supports, ix, 2, 20, 38, 54, 92, 112, 141, 185, 202, 226, 243, 268, 273, 293, 314
Symmetry, 96–99

T
Teacher agency, 23, 24, 27, 32, 33, 51, 58
Teacher autonomy, 25
Teacher community, 59, 190
Teacher competencies, 239
Teacher education, ix, 1, 24, 54, 201, 221, 244, 261
Teacher education life-long learning, 2
Teacher knowledge, 8, 10, 19–33, 160, 205–206, 208, 213–215, 243
Teacher-leaders, ix, 10, 65, 159, 185
Teacher leadership, 32, 188
Teacher learning, x, 8, 10, 20, 53–59, 189, 190, 192, 194
Teacher learning in community, 53–59
Teacher professional knowledge, 85, 144, 205
Teachers' and students' conceptions, 142, 249
Teachers and textbooks, 8, 37–51
Teachers-as-leaders, 19, 160, 162
Teachers-as-researchers, 32, 58
Teachers' autonomy, 85, 193
Teachers' communities, 206
Teachers' continuing professional development (CPD), 66, 67
Teachers edit textbooks, 8, 37–51
Teachers' knowledge, x, 3, 11, 12, 136, 142–144, 194, 205, 206, 222–224, 238, 265, 267, 268
Teachers' professional growth, 160
Teachers' roles, 8, 9, 12, 47, 213, 230, 295, 316
Teacher Zone of Proximal Development (T-ZPD), 205
Teaching and learning in the disciplines, vi
Technological Pedagogical and Content Knowledge (TPACK), 205–207, 209, 222, 232, 236, 243
Technology, vi, 1, 40, 91, 163, 186, 201, 221, 243, 261, 273, 295, 313
Technology difficulties, 195
Textbook development, 37, 51
Tools, ix, 20, 38, 66, 92, 143, 161, 191, 202, 223, 243, 262, 274, 293, 315
TouchCounts, 92, 95, 100, 101, 103, 104
TPACK, *see* Technological Pedagogical and Content Knowledge (TPACK)
Train the trainer, 188–190, 194
Trust, 11, 58, 68, 70, 112, 113, 120, 130–131, 187, 243–258, 261, 263, 265, 288
21st century, 10, 22, 24, 141, 142
21st century skills, 3, 71, 234, 274, 277, 286, 288, 294, 313

V
Virtual, 12, 97, 99, 128, 131, 134, 206, 245, 278, 294, 297–300, 302, 305
Virtual learning communities, 186

W
WhatsApp, 9, 112, 114–120, 122, 124, 127, 128, 130–136, 186, 192

Z
Zone of Proximal Development (ZPD), 205, 206