STEM Teachers and Teaching in the Era of Change:
Professional expectations and advancement in 21st Century Schools

Preface

'*A person has STEM literacy if she can understand the world around her in a logical way guided by the principals 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, with the aim to highlight 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. 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 inter-disciplinary curriculum practices built around authentic problems which involve some or all of them (Tyler, Swanson & Appelbaum, 2015). The skill-set 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 on the role of STEM teachers in the 21st century as they are asked to cope with cognitive, behavioural 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, S., Tytler, R., Freeman, B. & Roberts, K., 2013). The report firstly underlines that, while the countries strong in STEM (such as Finland, China, North Korea…) are diverse in their economies, political and social cultures and their educational traditions, certain features recur in common (ibid, p.15): school teachers enjoy high esteem, are well paid and work within meritocratic career structures; there is an unbreakable commitment to disciplinary contents so that teaching (and consequently professional development) is primarily focused on the knowledge of the discipline; 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, and emphasis is given to creativity and critical thinking; innovative policies have been developed to lift STEM participation among formerly excluded groups; strategic national STEM policy frameworks have been developed to provide favourable conditions for a range of 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: promotion of 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.

In 2009, lagging behind the US with some other countries and the growth of the high-tech industry, Europe has started to stir things up establishing a network, Scientix[1], so as to not leave European science-related school projects isolated, and to create a critical mass in favour 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 necessary to face this challenge from a strictly cultural point of view, while it is mainly the lack of adequate structures to prevent innovation in fast education and at the height 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 whose 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

[1] www.scinentix.eu

examples concerning improvement in the teaching of mathematics. In 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 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 of symbols without meanings. As a consequence, the school curriculum should lead students not only to the mastery of operative techniques but also to the ability to place these techniques in a theoretical framework that justify 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), with the collaboration of academic researchers and school teachers, as 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 mathematical 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. In this perspective, mathematical skills are seen as a set of processes based both on mathematization as a modelling 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 the STEM agenda are mainly carried out with the aim to provide students with operational concepts in order to develop mastery of skills as ‘processes’ structured into complex forms (reproduction, connection, reflection) and to help students develop skills in both reading and the production of mathematical texts 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 aims to bring coding and digital literacy to everybody in a fun and engaging way[2]. 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 of coding, however, goes on 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 the primary, 27% of the lower secondary level, while 15% of 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 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, to break down complex problems into smaller ones (decomposition), to recognize patterns (pattern recognition), to identify the relevant details for solving a problem (abstraction) or 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[3] points out, in Mathematics (figuring out the rules

[2] https://codeweek.eu

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

for factoring 2nd-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 in extracurricular time, breaks the traditional classroom practices and not only boosts students to interact and collaborate with each other, but also encourages teachers to cooperate.

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 — PNSD[4]). 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 recognised that teachers and school staff would have to be placed in the right conditions to act as a facilitator 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 and not suffer innovation. Teacher training, as a consequence, must focus on educational innovation, taking into account digital technologies as support for the realization of new educational paradigms and operational planning of 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 capillary throughout the territory, it is necessary to overcome the challenge of accompanying all teachers in the new methodological paradigms.

To conclude this overview, I would stress that, despite the presence of possible antibodies on which we can rely, as the era of change reveals itself with new challenges and new tools with which we meet them, in order to investigate the role and professional expectations of STEM teachers and the advancement in 21st 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-centred 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 fulfil, and, in my view, does so extremely well.

The manuscript, indeed, 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 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 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, indeed, 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 21st century schools.

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

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 teachers' professional expectations and teaching advancement in the 21st century.

From the first section, the empowerment of teachers by expanding their roles is advocated by the description of a project developed in Canada and a project developed in Israel. Moreover, the following discussion chapter brings to the fore general aspects which do not depend on the two particular experiences, 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 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 analysed in depth throughout the next two sections of the book.

Teachers Professional Learning Communities to support 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.

Section four 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 highlights the implicit acknowledgement 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. As a consequence, teachers should be constantly empowered to enhance their pivotal role in students' learning.

The last section 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-centred 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 pedagogies described. 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 the reading of this book to policy makers and STEM teacher educators, as it offers interesting theoretical considerations and practical proposals in order to break the vicious circle of reforms through: 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 teachers from STEM fields. 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 21^{st} Century schools.

Moreover, the book is also of interest for 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 robots, to subject-based software.

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