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Looking Back and Looking Forward: a Historical Perspective on Science, Mathematics, and Technology Education in Canada Through a Personal Lens

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Abstract This year (2020), when the *Canadian Journal of Science, Mathematics, and Technology Education* (CJSMTE) is turning 20, I am completing my 40th year in the field of science, mathematics, and technology education, initially teaching the school subjects and later conducting research from a learning sciences perspective. As I am looking back, it appears to me that despite all of our community's work and despite the collective efforts to innovate science, mathematics, and technology education (SMTE), many classrooms still are organized around the stand-and-deliver format as they had been 40 years ago. I account here how my own experiences in the classroom have contributed to the development of one line of my work on transforming classrooms; this work has been published almost exclusively in CJMSTE. I then outline some developments that I would pursue if I were to be in the field longer and that I deem important to be investigated by younger generations of SMTE researchers in Canada and beyond.

Résumé Cette année (2020), au moment où la Revue canadienne de l'enseignement des sciences, des mathématiques et de la technologie (CJSMTE) fête ses 20 ans, je termine ma 40e année dans le domaine de l'enseignement des sciences, des mathématiques et de la technologie. J'ai d'abord enseigné les matières scolaires, puis j'ai mené des recherches dans une perspective d'apprentissage des sciences. En regardant en arrière, il me semble que malgré tout le travail de notre communauté et malgré les efforts collectifs pour innover dans l'enseignement des sciences, des mathématiques et de la technologie (SMTE), le format d'enseignement dans de nombreuses salles de classe continue d'en être un où l'enseignant livre le contenu debout devant la classe, comme il y a 40 ans. Je raconte ici comment mes propres expériences en classe ont contribué au développement d'un axe de mes travaux sur la transformation des salles de classe, des travaux quasi exclusivement publiés dans le CJMSTE. Je décris ensuite quelques développements sur lesquels je me pencherais si je devais être dans le domaine plus longtemps et qu'il me semble important que les jeunes générations de chercheurs en SMTE au Canada et ailleurs étudient.

Keywords Canada · STEM · History · Theory · Practice · Change · Persistence

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As CJSMTE is accomplishing its first 20 years of existence, I will be completing 40 years of teaching and researching in the field. Our mutual trajectories repeatedly linked up and became immanent in each other. Here I present an account of this interlacing, the influences of my career as an SMTE teacher and researcher on my contributions to CJMSTE; and I end with a view on what I currently consider to be the most important task to be completed. During the early parts of the last four decades (1980–1992), I was teaching science, mathematics, and computer science spanning three Canadian provinces (Quebec, Newfoundland, and Ontario), whereas nearly three-quarters of that period was spent researching how people—including students—know, use, and learn to act in fields where the abstractive mind might find something related to science, mathematics, or technology. It was only during the first half of the existence of CJSMTE that I was still (somewhat) interested in doing research in formal educational settings; since then my interests shifted to investigate knowing and learning in everyday settings and beyond the topics of science and mathematics. In more than one way, I am thus looking at SMTE from the outside, having spent years of following around scientists, electricians, fish culturists, environmentalists, mariners, software engineers, and pilots. With those latter activities, my convictions have changed, having seen for example that constructivist theory—an important theory initially helping us to overcome behaviourist and cognitivist takes—and schooling itself are problems to be conceptualized and addressed. But, it seems to me that for many teachers and researchers, these "problems" are not even visible, having become integral parts of mainstream ideology.

Is there still a place to teach the SMT subjects separately from each other and other fields of human pursuits? During the summer of 2019, I received an email from a (well-published) science educator, whom I have known since his PhD years at an international institution where I had repeatedly visited and collaborated with colleagues. The email expressed that the end of science education as we know it is nearing. The content of the email needs to be looked at seriously because it will also affect the ways in which we envision the future of our own CJSMTE. When asking the colleague for further elaboration while writing these lines, I found out that these were the feelings numerous senior colleagues had voiced. Those senior colleagues were also concerned that much of the research conducted by junior researchers (PhD students) "present the same old stuff from 30 years ago." The note and our follow-up exchange led me to have a flashback: after successfully completing my PhD and publishing a number of pieces from it, I realized that the kind of work I had been doing thus far was nearing its end. I felt ill-prepared to pursue a university career, a feeling that led me to leave a first academic position and to return to the high school classroom where the beginning of my subsequent research career unfolded. The exchange with my colleague also made me think about how little science education research appeared to have brought about real change in the field over the 40 years since I had entered it as a science and mathematics teacher. Despite all the grand discourses concerning the integration of the parts of STEM, STEAM, or science and society, science still is taught apart from other subjects, at different times, and in different rooms (see below). That is, they are taught under the same conditions that have been shown to lead to decontextualization, disembodiment, and depersonalization of knowing (Roth & McGinn, 1998). In addition, there continues to be a focus on individual achievement. This focus leads to the fact that grades are the (intentional) objects of activity rather than knowing-to-navigate-a-particular-aspect-of-the-world, a fact that shapes—as any activity or practice theory will point out—the very ways of knowing and things known in everyday events where there never is timeout.

A tremendous amount of research has been conducted in Canada since the establishment of CJSMTE. During the 1990s, when the question arose whether the science education community needed another journal—especially one that appeared to have, as the adjective "Canadian" seemed to suggest, a more regional orientation—I was rather skeptical. Nevertheless, when CJSTME eventually came to life, I agreed to become a member of the editorial board. I did come to see that there was important work to be published in the journal, especially work that might not have been published in other, often US-dominated journals, because of the more critical stances CJSMTE authors have taken toward mainstream views. I have come to realize that CJSMTE, perhaps more than most other journals in the fields covered by the SMT acronym, has published interesting papers and special issues that question the status quo. Those publications that I have found particularly interesting was a set of papers presenting (Fensham, 2002) and discussing what ought to be the driving elements in thinking about and teaching scientific literacy (CJSMTE vol. 2, issues 1 and 2). The journal editors continued that particular focus on rethinking education from a variety of perspectives, including the special issues "Activism: SMT Education in the Claws of the Hegemon," guest-edited by Steve Alsop and Lawrence Bencze (CJSMTE vol. 10, issue 3), "Rethinking Education for Citizenship" (CJMSTE vol. 15, issue 3), guest-edited by Hagop Yacoubian and Jesse Bazzul, and "Mathematics Education in the News," guest-edited by Yasmine Abtahi, Richard Barwell, Janelle McFeetors, and Lynn McGarvey. It remains to be seen whether some of the more recent reconceptualizations of SMTE will bring about, in Canadian and international SMTE, a difference that makes a difference. But those efforts to rethink SMT literacy from a societal perspective may have some followings that differ from the many other movements with their number of followers.

Looking Back

"Plus ça change, plus c'est la même chose?"

Has SMT education in Canadian schools changed since the time I started? Is it something we might have expected to have occurred given all the research that has been published in the 40 years since I started teaching? Real change does not seem to have occurred, or, as the French say in the proverb that entitles this section, "Plus ça change, plus c'est la même chose (literally, The more something changes, the more it's the same)." As I am looking back at SMTE in the way I experienced being a member in the school community, later a researcher continuing to teach, and now visiting classrooms every now and then, I feel that little has changed—despite all the efforts of SMT educators in teacher training, in-field support, and research on teaching and learning. In the fall of 2019, I had the opportunity to visit, together with a colleague who had arranged it, an eleventh-grade course on earth science in the province of British Columbia taught by a young teacher, with just about five years of experience after graduating. It was early in the school year, and the course apparently was working on what the provincial curriculum guideline specifies among its *Learning Standards* in terms of the content: "properties of earth minerals—minerals, igneous rock, sedimentary rocks, metamorphic rocks, geologic resources" and "surface and internal processes of the rock cycle" (BCME, 2018, p. 1). The focus of the lesson clearly was on what the provincial curriculum lists in the *content* column of the Learning Standards, but the curricular competencies appearing in another column of the Standard quite apparently were not addressed in this course. Among the curricular competencies, many of which are concerned with the different aspects of inquiry practice, none seemed to fit what I was seeing. The students were asked to use scissors for cutting concept words from a handout and to assemble those into what students thought was "the rock cycle."

During the 20 minutes allotted, the students were handling their phones, some were grooming themselves or peers, still others were unpacking what might have been their first meal of the day, and others again left the class for considerable amounts of time to go to the washroom. There appeared to be little going on to match what the Learning Standards according to which the students are to "demonstrate a sustained intellectual curiosity about a scientific topic of personal interest," "make observations aimed at identifying their own questions, including complex ones, about the natural world," and "formulate multiple hypotheses and predict multiple outcomes" (BCME, 2018, p. 1). Indeed, many students did not appear to have heard about the cycle (the teacher said, "Have you forgotten…?") and thus, they would have been unable to do anything like a group concept map, as I had pioneered while still teaching at the secondary level (cf. Roth & Roychoudhury, 1992).

Upon leaving the classroom, my colleague and I talked about how uninspiring and boring we had found the lesson and that we were not surprised about having seen so little student engagement. We were talking about another teacher in whose class we had been and whose lessons had been pretty boring until he had been paired with another teacher and learned to facilitate more interesting lessons. Despite all the theoretical rhetoric, much of SMT teaching did not seem to have changed; and the impact of research has been small.[1]

One of the assumptions often made in SMT teaching is that hands-on activities increase student engagement because students are "having fun." But, as research with my former PhD student Giuliano Reis (now University of Ottawa) has shown, what teachers design as fun often is not experienced as such (Roth, van Eijck, Reis, & Hsu, 2008, chapter 4). With Giuliano, we looked at outdoor experiences offered by and through an environmental activist group. Although we had expected to see lessons that would capture students' interest in environmental issues, what we observed was a little different from what students were experiencing in their classroom. Students remained just as unengaged and peripheral to SMT as in their regular classes. Research conducted with other colleagues over the past half dozen years in two arts-based elementary schools also provided me with evidence for a lot of teacher-controlled lessons, with occasional verification exercises that provided students with few opportunities to explore, talk, and learn science. The same dreary picture emerged when, a few years ago, I videotaped a week-long science summer camp designed by a science education researcher with a PhD degree and taught by a science graduate student and an experienced elementary teacher. Though explicitly designed to provide fun as part of the activities of an organization trying to combine science and fun, the summer camp did not provide children with much positive experiences: many were disengaged from the moment they were dropped off in the morning. A number even asked their parents to take them back home, and others quit partway through the week.

Perhaps I should not have been surprised knowing what I have learned about curriculum development and teacher preparation. University-based SMT educators tend to perpetuate what they are familiar with, training future teachers along the lines of what they themselves have come to know. Teachers, too, stick to what they have done for many years. Thus, I have attended meetings around 1992 and 1993 with teachers whose discourses in teacher meetings were consistent with constructivism but who, in their classrooms, still stood up and delivered using, as they proudly declared, the same overheads as they had before their adoption of constructivist theory. A further case in point is the development of science and mathematics curriculum that I was able to see from close up because I came to know in person the people in the British Columbia Ministry of Education responsible for curriculum development and the processes by means of which new curriculum was written. "New" curricula were produced involving ministry officials and senior teachers from the province, who were drawing on what they had learned themselves decades before. Thus, though initially surprising to me that even during the second decade of this century there were curricula that have had Bloom's taxonomy as their essential theoretical framework. A quick look into the internet shows that there are still teacher education programs perpetuating the taxonomy, though it has no foundation in the work on situated and everyday cognition that has become available from the 1980s onward. More importantly, perhaps, I had told those ministry individuals about more innovative ways of teaching (see below) and about recent research—with no apparent effect on what was happening in BC curriculum development.[2] This also questions whether what we publish in journals such as CJSMTE has any relevance to SMTE in the field. Whatever the answer to that question, we need to find out how and why there is the level of impact observed.

Teaching Differently than I Had Been Taught: Practical and Theoretical Advancement

My own teaching and thinking had taken a different trajectory and independent of what SMT research had reported and whatever SMT teacher educators might have been thinking at the time. I had come to the field

[1] In the USA, for example, the National Science Foundation has spent large amounts of money on SMT (STEM), and yet there exists in that country an enormous climate denier industry (Readfearn, 2015); and a not-to-distant poll showed that 42% of US citizens hold non-scientific, creationist views of the human origins (Gallup, 2015).

[2] Interestingly enough, some 15 years later, the ministry repeatedly drew on the (costly?) services of a UK consultant for its new twenty-first century learning vision, which was based on ideas that I had previously contributed to elaborating.

as a research scientist (MSc in physics) without an education background. Not having had teacher training[3], my career as a teacher of SMT subjects and my approach to the curriculum (planning, enactment) had been shaped by my biography. I had to repeat fifth grade, in part because of mathematics, but later reasonably successfully finished the secondary and college levels before doing the Master's degree in physics with applied mathematics and chemistry as minors. I had realized at the end that the most interesting time of the 19 years I had spent in school and university had been the final year when I did the research for my MSc degree. Before that, I had come to know SMT subjects as boring, a lot of stand-up-and-deliver contexts with a few verification exercises as laboratory activities. The mathematics classes I experienced all had been in the stand-and-deliver format. When I started teaching in Quebec, I saw the same happening in the classrooms of my fellow teachers; and I continued seeing this approach later after moving to different provinces.

When I was looking for a job in Montreal of the late 1970s and early 1980s, jobs were scarce in part because of an economic downturn. Even though I had no education or psychology background, I was looking for a teaching position. However, the Montreal school boards were laying off teachers with less than 12 or 13 years of experience. But in the north of the province (Quebec), which had high turnover rates in teachers, there was a demand; and I landed a position as a science and mathematics (and some other subjects) teacher. From the beginning, I wanted to provide learning environments that resembled my own graduate student research—which led me to teach through inquiry, in part driven by students' own questions. In mathematics, faced with students of widely varying abilities (in grade 8, from non-reader to reading at tenth-grade level), I organized students into groups that determined their own weekly learning targets, with each group having its own examinations during the compulsory examination periods. As a result, the slowest group covered the entire curriculum at a mastery level (80%), and the fastest group covered about half of the ninth-grade curriculum. Later, teaching computer science in Newfoundland, I was moving to two-week contracts, allowing students to work when, where, and on what they felt like.

During the 1983–1984 school year, my then assistant superintendent had observed that many of my students in our impoverished Newfoundland town with a youth unemployment (18–25 years) of 75% were coming back to school in the evening and staying there until I locked up some time between 10 pm and midnight. He was asking me about my teaching, which led me to describe the student-centered approach, the contract-based system, the hands-on focus, etc. He told me about wanting to see more of this in our school board and that I should strive to become an SMTE curriculum specialist at the board level. Because this required a graduate degree on educational issues, he arranged the administration of the Graduate Record Examination (GRE) in our town; and he was key in identifying a graduate program that would have allowed me to get a PhD without little interruption of my regular work. Having in mind to become a change agent in SMTE, I did a PhD on the development of mathematical reasoning in adults in the College of Science and Technology at the University of Southern Mississippi (Hattiesburg, MS). I eventually decided to do a PhD full time and, given the twists and turns life tends to take, never returned to that school district.

After attending graduate school fulltime for 18 months (1986–1987), I returned in 1989 to the classroom in an Ontarian private school further advancing the teaching approach and, as the department head of science working with other teachers, to develop more student-centered approaches.[4] One of the teachers was G. Michael Bowen (Mount Saint Vincent University), with whom I did some of the classroom-based research in teaching and learning in open-inquiry settings, where we looked, among others, at the mathematization of experience in science lessons (e.g. Roth & Bowen, 1994). In my physics classes (as in Michael Bowen's biology courses), students were designing their own experiments (70% of class time) and met me in small groups when they felt they needed help with formal concepts and the preparation for the

[3] During my first four years of teaching, I completed 10 undergraduate courses at various universities in eastern Canada to fulfill the requirements for certification in the different provinces I taught.

[4] After my PhD, I had started a second one in physical chemistry and then took up an academic position prior to returning to the classroom.

provincially required examinations at the end of the school year. In my last year as a physics teacher, during the time allotted by the provincial curriculum to the study of electricity, students spent a week on designing their own curriculum, nearly five weeks on completing their scheduled work, with one (long) period spent on presenting their work. There were three evaluation components, namely self-evaluation (5% of the grade), evaluation by peers (60%), and evaluation by the teacher (35%). For the evaluation by peers, each group presented their work to others and in one case where students designed a fifth-grade curriculum, their teaching the unit in an actual class was part of the evaluation process.

During the nearly 30 years of doing research, I had never found anything like this again, though my school visits and videotaped data derived from different countries, including Canada, USA, Australia, Germany, Norway, and Finland. The one example of teaching that I liked was featured in a French television documentary. After reading an article in which we theorized learning communities (Roth & Lee, 2006), which used examples from the one-village elementary school, the teacher wrote me an email saying that we had understood what he was trying to do better than other fellow countrymen. Some change may be visible at the horizon, though. I recently read a Spanish newspaper article about the latest approach in Finnish schools, well-known for their high PISA achievements in science and mathematics (Silió, 2019). The article described how even young students are involved in how and what they learn and how they share their work with students from the same and other classes. In a German magazine, I read about a public school that had abandoned traditional organization into classrooms favoring open spaces and individual, learner-designed curriculum programming, where the inhabitants of the spaces distributed over the town include *learning partners* (formerly students) and *learning attendants* (formerly teachers) (Willenbrock, 2020). Students choose what to do and learn at their own rates. Just as it had happened in my experimental teaching in Victoria (British Columbia), where students were contributing to the environmental activism in the community, and where community members came to school for talks or to work with the students, there is an interpenetration of community and school in the German case. Just as in my own teaching and research, “weak” and “disabled” students tend to learn a lot more than they do in normal classrooms (e.g. Roth & Barton, 2004, chapter 6). In the French, Finnish, and German case, students learn while engaging in cross-curricular projects rather than receiving instruction in specific subject matter.

As the department head of science in the private school, I also had changed the obligatory teacher evaluation from one in which the department head decreed an assessment to one that included four components: teacher self-evaluation, observation in another classroom, coteaching with a peer in another class, and department head evaluation assembled in a portfolio. One of the teachers, who not only visited my classroom but also had his own right next door, found that my classroom “always was a mess”—only to tell me when I left the school that his own teaching had changed because he had seen benefits in taking up some of the ideas I had been standing for. Though my colleague was seeing a messy classroom, the person from the ministry of education responsible for evaluating and certifying me not only commended what he had seen to the school administrators but also recommended to the heads of other schools in the area (Toronto, Hamilton, and St. Catharines) to visit my classroom. At that time, I had contacted the science educators of several universities in nearby cities—but there had been no interest at all in investigating teaching, learning, and learning to teach in such an environment. I therefore took it on my own to conduct research in my classroom, which then became the beginning of a new career as a researcher allowing me to take a university position by 1992.

Educating Teachers to Teach Differently

As a professor, I generally taught research methods courses at the graduate level.[5] However, I once accepted an assignment of an advanced methods course in science teaching at the elementary level that was offered to

[5] As part of my PhD, I had obtained a specialty in quantitative research methods, which was my teaching area at Simon Fraser University (1992–1996).

students as an extension for receiving an SMTE specialization (in British Columbia). To accommodate the need of the department in which my research chair was housed, I had previously taught experimental units lasting 3–5 months on a variety of topics in BC elementary and middle schools in the context of doing research on learning in student-centered environments. I repeatedly brought video clips from those lessons to view, discuss, and critique them with the future elementary school science teachers. I was stunned by the responses of the teachers-to-be: I should now tell them something that they could do so that they would be successful. The teachers-to-be were telling me that they could indeed see how that the teaching was working, but that they would not be able to teach in such a manner. That is, they intimated that they would not be able to provide the kind of the learning environment I had offered to my students. I thus could see a plausible reason for why there might be relatively little change in the practice of SMTE. Even if there are models and without an emphasis on the associated theory, teacher candidates might find it difficult to teach in the ways that those thinking and writing about SMTE envision it.

I have seen, however, that change is possible. One of the ways in which change can occur is through *coteaching*, which had been for me a way of assisting new and more experienced teachers in Vancouver and Victoria unfamiliar with student-centered approaches to make possible interesting science lessons (e.g. Roth, Masciotra, & Boyd, 1999). This is a way of teaching where each participant takes part in the joint responsibility for all aspects of teaching from planning to evaluation. Thus, coteaching does not mean splitting up a task so that teaching occurs in an additive fashion, where one individual does some aspects (e.g. grading) while the other is doing another task (e.g. having a whole-class discussion). For example, coteachers realize that teaching might be enhanced by a question, an additional drawing on the chalkboard, or by adding a correction to what another coteacher has said, then they step in to make the addition to the lesson happen. My research in Canadian schools has shown that new and experienced teachers can change to more student-centered approaches—e.g. developing questioning practices in open-inquiry learning environments that allow students to articulate and develop ideas in science (Roth, 1996). There is ample research—some of which we had and still are conducting in Canada, e.g. with Carol Rees, Thompson Rivers University (Rees & Roth, 2019)—showing that new teachers are becoming competent SMT educators teaching consistent with recent SMTE research.

From Practical Experience to Revisioning SMTE in Formal Publications

The advances of my own thinking about SMTE had their roots in my own classroom and have been accentuated during the 3–5 months long in elementary and middle school in British Columbia. Many of those ideas, often going against the mainstream, were published in CJMSTE. Early on, and based on a strong formulation of situated cognition (Roth & McGinn, 1997), I had felt that open-inquiry and student involvement in curriculum design and evaluation were not enough and that SMT education needed to be taken beyond schooling by allowing students to participate in the everyday affairs of their community because students would be learning those SMT-related skills that are used and useful for coping with everyday life (Roth, 2002). I had written the article in response to a piece by Peter Fensham (2002), for which the then editor Derek Hodson had invited a range of comments. Factoring polynomials and memorizing rock forms may not be among the most useful things in these contexts. Together with Jacques Désautels, I subsequently was working out how SMTE practices could arise together with concerns for citizenship (Roth & Désautels, 2004). Jacques and I contested the dominant approaches to SMT literacy, defined in terms of what scientists, mathematicians, and engineers know, produce, or do. We argued that a more viable approach to rethinking SMTE ought to frame a general project of (democratic) citizenship and then move to ask what kind of SMT literacy can contribute to this project.

My thinking did not stop there. I had edited a book that focused on science education *from* people and *for* people, especially as these were taking a stand or standpoint (Roth, 2009). It had appeared to me that democratic citizenship could be interpreted in a passive way, where individuals are reduced to go to the ballot box but do not otherwise contribute to the common good. Instead, *active* participation in our

(Canadian) society had become central to me: working toward a society in which individuals actively take up positions, defend their own rights and those of others who are not in a position to speak for themselves. In CJMSTE, I was working out how *activism* could be a theoretical framework for understanding SMT learning (Roth, 2010).[6] I expressed my sense that true, practical understanding is the result of the (ideal) reflection of the process and product of materially transforming the world. In this context, activism implies not just knowing something abstractly but being able to concretely and knowledgeably participate in real-life problems at hand.

Since the mid-1990s, and increasingly so, I developed the sense that SMTE research really had been nothing more than improvements in attempts of building better mousetraps and felt that educators needed to go further. In my last contribution to CJMSTE, I outline the sense that the institution of schooling is the real problem (Roth, 2015). This is also the sense that transpires from the description of the Finnish and German school examples provided above. Schooling re/produces the failures to learn and, thereby, contributes to the re/production of inequities that it (schooling) is supposed to overcome—and this includes the physical setting. Thus, the above-noted German school—making use of some new spaces but also drawing on existing spaces throughout the community—is based on the idea that space is a third pedagogical force (besides learning partners and attendants) and on the suspicion that building vandal-safe schools will yield vandals (Willenbrock, 2020). In my article, I show how the origin of inequities lies in societal relations, which are relations of ruling. I suspect that the real changes of schooling therefore do not come from this or that curricular change but arise from a reformation of schooling as societal activity generally and science and mathematics education specifically. In such a school reform project, journals such as CJMSTE have an important role.

Looking Forward: Some Necessary Developments in Theory

> All attempts to surmount—from within theoretical cognition—the dualism of cognition and life, the dualism of thought and once-occurrent concrete actuality, are utterly hopeless. (Bakhtin, 1993, p. 7)

Entity-Oriented Theories are Problematic

How do we go forward and where do we go with research in SMTE and, thus, with the kinds of contributions that are submitted to CJSMTE? From the perspective of my 40 years in Canadian SMT teaching and research, the most pressing need is to think about and theorize the real *being* of students and teachers as *events* rather than reducing these issues to constructions, mental frameworks, identities, emotion, that is, to thing-like entities with outside forces added to make them do anything. The activism framework outlined in my CJMSTE article (Roth, 2015) requires that we understand SMTE issues in the unfolding, complex life of the person. Today, however, SMT educational issues—identity, knowledge, practice, affect, tools, signs, meaning, etc.—still are investigated as if they were things independent of other things that exist in the classroom, school, and general life of the student and teacher. Studies focus on how a particular technology supports mathematics learning, or how a student in a particular program develops a “science identity.” As the introductory quotation suggests, this move will not be possible from within theoretical cognition. This move thus will be a major challenge for SMTE, for doing so will take the community to and beyond the limits of constructivism (e.g. Roth, 2011). It requires us to theorize who we, real people, think, talk, do, and feel in real everyday situations in which we do not abstract what has happened and

[6] The article received the Canadian Association for Curriculum Studies award 2011, for "its theoretical sophistication and nuanced attention to activism, its poignancy, its relevance to both the Canadian and international context and its potential for forging new ground by transforming pedagogy and curriculum (e.g. through addressing important environmental and ethical issues)."

concurrently is happening. We have to think about ourselves, participants in and attendants of learning, as living beings always caught up in a continuously unfolding life where there never is time out and where cogitation and meta-cognition are rather uncommon. This includes events when teachers are struggling (and thereby learning) to find the right question (e.g. Roth & Radford, 2010) and events when learners get frustrated because they do not know where what they are doing is supposed to lead (e.g. Roth & Walshaw, 2019). We have to think about being, identity, thinking as events permeated by affect. Once we begin thinking about identity-as-event, it is no longer possible to conceive of someone "having" a science or mathematics identity, because whatever this means it cannot be more and different from a snapshot that fails to capture the nature of the phenomenon precisely because of the nature of the snapshot (i.e. it is a *still*). It also makes no sense to talk about how students or teachers "construct" something, because that very construction presupposes the subject, the thing to be constructed existing ahead of the event in the mind, and the verb that does the conversion of what has been thought about into something materially present.

Throughout my life, I have been seeking integration across disciplines and consistency between my life as I experienced it and the theories that my field of inquiry was using to understand the kinds of activities I was involved in (knowing, learning, including in SMT areas). Ever since my PhD studies, I have felt that existing theoretical frameworks were not capturing how I was really experiencing life, and what being-in-the-know and coming-to-know really meant. For example, even though and perhaps precisely because I was a fervent constructivist at some time (radical, then social), I experienced the gap between what my colleagues and I were writing about learning (e.g. "constructing" knowledge) and what was really going on. Very clearly, because I did not and could not know what I would know at some later point in my life, I could not actively orient toward it. It has been only recently that I have come to understand why all currently used theoretical frameworks—many of which have been central to my own work over the years[7]—fail to get at the very being alive of living, breathing, and learning in the SMT fields. Already in the 1930s, there existed the realization that when knowing (and learning) are considered on their own, apart from actual, practical, intellectual, and affective being-alive, "the cognitional act comes to be governed by its own immanent laws" (Bakhtin, 1993, p. 7) and "thinking itself [becomes] the thinker of thought" (Vygotsky, 1987, p. 50). Both authors sought the answer to the problem in the same direction: consciousness and thinking needed to be investigated within "the full vitality of life," in the context of "the motives, interests, and inclinations of the thinking individual" (p. 50), that is, "within the historical context of [their] actualization" (Bakhtin, 1993, p. 7).

Prepared by my engagement with Bakhtin but ultimately through my reading of Alfred North Whitehead and William James, I have come to realize that all theories of learning used in the SMT literature have a focus on the subject, who is to learn to know the same basics as all other subjects. Comparisons between subjects (or experience)—which can be completed only when the subject is indeed independent from all other subjects and the world—inherently take the thing-centered approach. Events, however, when they exist separate one from the other, have nothing to do with each other (Whitehead, 1919); no third thing, like sign, can bring separated entities back together via "mediation"; any third thing but proliferates division into things and gaps that separate them (James, 1909). And when events cannot be separated because they are co-constitutional, they inherently make impossible any consideration on their own. A clear and easily understandable example exists in the case of a person said to have been killed by a shot from a handgun (Dewey, 1938). The shot itself cannot be the cause of death, for there are many shots not associated with the death of a person; and any intended shot could have missed the person. The intimation of a causal effect may only be done by a bullet that actually enters a body such that it entails the cessation of all vital functions. However, "such an event is not an antecedent of the event of dying, because it is an integral *constituent* of that event" (p. 449). Exactly the same suggestion has arisen from the analysis of engineers and scientists at work, which showed that any coincidence between (mental) plans and scientific practice can be established

[7] Piagetian constructivism, information processing, (radical) constructivism, discursive psychology, cultural-historical activity theory, (Vygotskian) socio-historical theory, embodiment, and enactivism.

only after the fact; as a consequence, the plans of the engineers and scientists could not have been the causes of their actions (e.g. Suchman, 2007).

A Focus on Being-Alive: Starting Points for Theoretical Change

What do we need for a theory of learning that is consistent with the ways of becoming-in-the-world? To reverse the commonly practiced (theoretical, epistemological) reduction and to highlight that events rather than things (subjects, objects, actions) are considered, Bakhtin (1993) colligated existing noun forms to the gerund "being." He thus arrived at new formulations including world-as-event, life-as-event, being-as-event, or Italy-as-event. The world, being, and Italy no longer *are* (e.g. things with stable characteristics) but *are-becoming*, events continuously in movement and thus *themselves* changing. Here is not the place to articulate what has been done so far (see, e.g., Roth, 2019, 2020). In the following, I detail some of the basic ideas of thinking about SMT events in terms of events, flux *in terms of* flux, and becoming in terms of becoming (including novelty). Thinking about people as family of events, relating to each other because they (their experiences) are intersected by some common event (e.g. talking), will explode thinking about people as things with characteristics (intellectual, affective, practical). An "individual" no longer *is* but *is-becoming* as continuity of living experience, an event always intersecting with other experiences and events such that what happens in a lesson cannot be disconnected from the history of experiences or from all of the other continuing experiences. When in mathematics class, "a" student is not disconnected from the experience of living within an abusive parent or family, cannot be thought apart from the experience of having only one meal a day, or separate from the experience of bullying that is present even though its outward forms end with the entering in the classroom and begin again upon leaving the room (cf. Roth & Radford, 2011).

Consider the becoming of a square from tangram pieces in a second-grade mathematics classroom (Fig. 1). The stills intimate how from the various tangram pieces, handled and held by a student and a visiting professor, emerges a perfect square. The biggest mistake we can make, and which tends to be made on a daily basis in our research culture, is to theorize the event of pieces-becoming-square-in-the-hands-of-a-living-student in terms of these stills. It is a mistake because thinking so is but to reiterate the patterns of thought appearing in Zeno's paradox. In more recent terms, it is the fallacy of thinking about events in cinematographic terms. But those images we observe on the video (e.g. the one from which Fig. 1 was constructed) are stills, and what we see has movement on the screen (monitor) is the result of a *projector* or outside *mechanism* that presents the stills quickly enough so that there *appears to be* movement (Bergson, 1908). How can movement emerge from something that is not movement? Only if there is some *outside* force (e.g. movie projector). But what we are missing then are the very *inner* movements that make the event a living one with its own inner dynamic.

In current theories even those focusing on practice, events are not thought as events but in terms of subjects (objects) and their actions (processes) external to them, a critique that was first articulated in the modern era during the nineteenth century. Thus, instead of considering lightening as event, the Greco-Roman tradition has come to think about a flash (thunderbolt) that is lighting up the sky. But in saying that "'the thunderbolt is lightening,' I have posited lightening once as activity and once as subject: that is, to the event was added a subject that is not one with the being, but rather *remains*, *is*, and does not '*become*'" (Nietzsche, 1922, p. 43). The issue also has been articulated in terms of human development (Bergson, 1908). In saying "the child becomes an adult" (p. 338), an event is reduced into a subject (child), a verb, and a state (adult); once adult, "child" is a state external to the subject. It is a cinematographic approach, where different states (e.g. frames in Fig. 1) only seemingly come to life because of the external movement of the projector, the purpose of which is to rapidly superpose successive *stills* so that it looks as if there was movement. A focus on the event would occur if we were to say, "there is becoming from the child to adult" (p. 338). In the former view, developing (how to bring it about and understand it) is a problem, whereas, in the latter view, knowledge and the states of development are the problems.

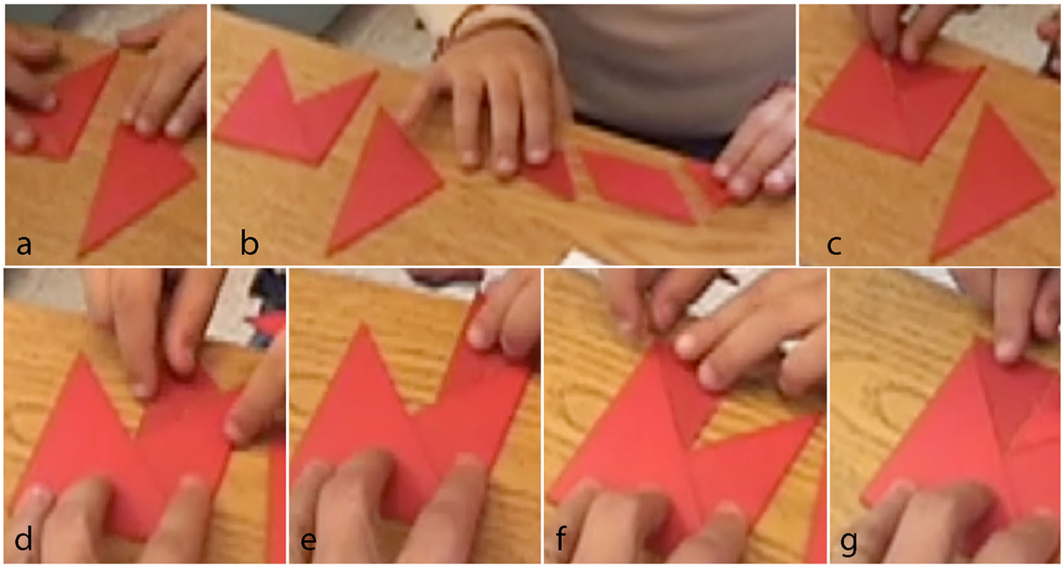

Fig. 1 **a**–**g** Becoming of a square from tangram pieces involving a second-grade student (hands entering frames from the top) and a university professor visiting the class (hands reaching into the frames from the bottom)

An important aspect of the evental view is that there is novelty between any two actual or thinkable photographs. An event, however short it may be, inherently constitutes a *creative* advance and, therefore, *always* introduces the unexpected (Mead, 1932; Whitehead, 1920). Novelty means that some future instant (e.g. a student reply) *cannot be* predicted based on what currently exists and is known (e.g. when the teacher initiates). Any next instance, however small the temporal difference, includes something that was unforeseeable at the present instance. All you have to think about are the many smaller and bigger "accidents" that occur to us in everyday life, the tipped-over wine glass, the laptop dropped, the keys forgotten. But this unpredictability even of the most immediate future arising on our current horizon has not entered any theories of learning and teaching, though the fact has serious implications for both areas. Thus, for example, students cannot know what they will know even seconds hence, which limits any possibility to be metacognitive about their learning. Teachers, too, do not know what any of their words and phrases will solicit from their students—as seen from the fact that they often repeat questions in new forms, or abandon questions to be replaced by other more appropriate ones—as we have shown through investigations in Ontarian French-immersion mathematics classrooms (Roth & Radford, 2010). Teachers learn (change) while teaching, and students are important parts in making such learning happening.

From experience, I know that the evental view does not come easy both because of the success of the thing-oriented view in human history consistent with a will to power (Nietzsche, 1922) and because overcoming a cherished and long-held view is challenging (inherently involves exposing oneself to uncertainty, novelty). What is difficult about the view is that change itself is the fundamental unit. Take the situation described above. Rather than thinking about the student as using the pieces and constructing something, we not only consider there to be a world in flow but also, when considering it, we take the event as a unit (Fig. 2a). When looking at such a unit, it is apparent that we cannot say something about *it* or *its characteristic*, because how the unit looks like depends on when, where, and how we look (take a photograph). We already saw this in the stills grabbed from the videotape. Each one is a valid manifestation of the *same* unit. We can look at parts of the event as long as that part also is an event (Fig. 2b). Importantly, these smallest events (a) contain novelty over and above any determinate aspects of change between beginning and end and (b) in any two consecutive ones, the later arises *in* and *out of* the earlier one (Fig. 2c). In the second case, because the two nanoevents share aspects, the later one cannot have been *caused* by the earlier one, though the earlier has been part of the conditions for the later one to occur (Dewey, 1938).

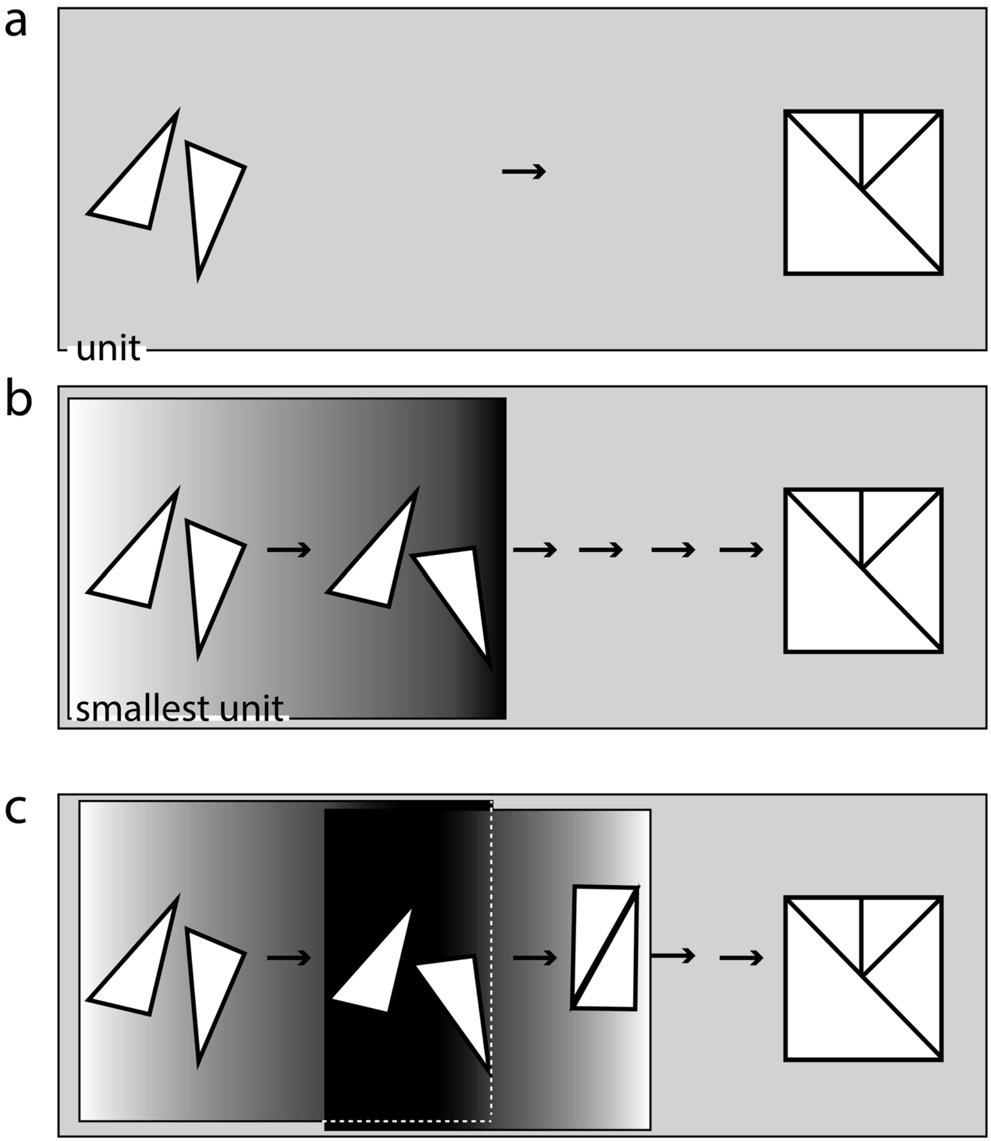

Fig. 2. **a** The evental view requires units that incorporate change, that is, *becoming*. **b** The very smallest unit still has to embody change, working against any attempt to see how something *is*. **c** The smallest unit overlaps with that following it (dark area), so that the subsequent arises *out of* the earlier one but, because they have parts in common, is not *causally* determined by it

Because the view requires us to always look at an event and thus change, we cannot reduce the episode to the tangram pieces and their arrangements at some "beginning" (Fig. 1a, Fig. 2a) that are somehow used or transformed by an agent.

In the sense developed here, even a test, the results of which frequently are represented in individual numbers (e.g. achievement as measured by a PISA examination), is an event. This event is not captured in the number, and the number cannot claim to represent any characteristic of the person—at a minimum, it arises from the conjunction of the testing situation and the person and thus is a characteristic of both (Bateson, 1979; Snow, 1992).

One of the consequences of the evental view is that—consistent with our experience of how life works, appears, and feels like—no individual is in (complete) control of an event as a whole. Only if everything in a situation is conspiring in a way consistent with one actor, then one might get the impression that it was this actor who was responsible for the change. Any teacher is only part of the situation as a whole, and what transpires does so because any subject also is subject and subjected to the situation as a whole.

Coda

Over the 20 years of its existence, CJSMTE has published important papers and special issues. There is a place for continuing in this endeavor even though, at this point in time, there appears to be little that has changed in classrooms, many of which still are reigned by the stand-and-deliver approach and focused on grades and grading. However, by reading and contributing to the journal, Canadian and foreign SMTE researchers will begin to change, and these changes should come with modifications in the way they prepare future teachers. Although my time for contributing to this endeavor is near its end, there are many much younger researchers—including some of my own graduate students—who have it in their hands to contribute to a changing field.

Compliance with ethical standards

Conflict of Interest The author declares that he has no conflict of interest.

References

Bakhtin, M. M. (1993). *Toward a philosophy of the act*. Austin, TX: University of Texas Press.

Bateson, G. (1979). *Mind and nature: A necessary unity*. New York: E. P. Dutton.

Bergson, H. (1908). *L'évolution créatrice* [Creative evolution]. Paris: Félix Alcan.

British Columbia Ministry of Education (BCME). (2018). Area of learning: SCIENCE—Earth sciences. Accessed at https://curriculum.gov.bc.ca/sites/curriculum.gov.bc.ca/files /curriculum/science/en_science_11_earth-sciences_elab.pdf

Dewey, J. (1938). *The logic of inquiry.* New York: Henry Holt.

Fensham, P. (2002). Time to change drivers in scientific literacy. *Canadian Journal of Science, Mathematics, and Technology Education, 2*, 9–24.

Gallup. (2015, June 2). In U.S., 42% believe creationist view of human origins. Retrieved from https://news.gallup.com/poll/170822/believe-creationist-view-human-origins.aspx

James, W. (1909). *A pluralistic universe*. New York: Longmans, Green.

Mead, G. H. (1932). *The philosophy of the present*. Chicago: University of Chicago Press.

Nietzsche, F. (1922). Nachgelassene Werke: Zweite Abteilung Band XVI [Unpublished works. Part 2 vol. 16]. Leipzig: Alfred Kröner Verlag.

Readfearn, G. (2015, March 5). Doubt over climate science is a product with an industry behind it. *The Guardian*. Retrieved from https://www.theguardian.com/environment/ planet-oz/2015/mar/05/doubt-over-climate-science-is-a-product-with-an-industry-behind-it

Rees, C., & Roth, W.-M. (2019). Discourse forms in a classroom transitioning to student-centred scientific inquiry through co-teaching. *International Journal of Science Education, 41*, 586–606.

Roth, W.-M. (1996). Teacher questioning in an open-inquiry learning environment: Interactions of context, content, and student responses. *Journal of Research in Science Teaching, 33*, 709–736.

Roth, W.-M. (2002). Taking science education beyond schooling. *Canadian Journal of Science, Mathematics, and Technology Education, 2*, 37–48.

Roth, W.-M. (Ed.). (2009). *Science education from people for people: Taking a stand(point)*. New York: Routledge.

Roth, W.-M. (2010). Activism: A category for theorizing learning. *Canadian Journal of Science, Mathematics, and Technology Education, 10*, 278–291.

Roth, W.-M. (2011). *Passibility: At the limits of the constructivist metapho*r. Dordrecht: Springer.

Roth, W.-M. (2015). Schooling is the problem: A plaidoyer for its deinstitutionalization. *Canadian Journal for Science, Mathematics, and Technology Education, 15,* 315–331.

Roth, W.-M. (2019). *Transactional psychology of education: Toward the social in a strong sense*. Cham: Springer.

Roth, W.-M. (2020). Adventures of mind and mathematics. Cham: Springer
Roth, W.-M., & Barton, A. C. (2004). Rethinking scientific literacy. New York: Routledge.
Roth, W.-M., & Bowen, G. M. (1994). Mathematization of experience in a grade 8 open-inquiry environment: An introduction to the representational practices of science. *Journal of Research in Science Teaching, 31*, 293–318.
Roth, W.-M., & Désautels, J. (2004). Educating for citizenship: Reappraising the role of science education. *Canadian Journal of Science, Mathematics, and Technology Education, 4*, 149–168.
Roth, W.-M., & Lee, Y. J. (2006). Contradictions in theorizing and implementing "communities." *Educational Research Review, 1*, 27–40.
Roth, W.-M., Masciotra, D., & Boyd, N. (1999). Becoming-in-the-classroom: a case study of teacher development through coteaching. *Teaching and Teacher Education, 17*, 771–784.
Roth, W.-M., & McGinn, M. K. (1997). Deinstitutionalizing school science: Implications of a strong view of situated cognition. *Research in Science Education, 27*, 497–513.
Roth, W.-M., & McGinn, M. K. (1998). >unDELETE science education: /lives/work/voices. *Journal of Research in Science Teaching, 35*, 399–421.
Roth, W.-M., & Radford, L. (2010). Re/thinking the zone of proximal development (symmetrically). *Mind, Culture, and Activity, 17*, 299–307.
Roth, W.-M., & Radford, L. (2011). *A cultural-historical perspective on mathematics teaching and learning*. Rotterdam: Sense.
Roth, W.-M., & Roychoudhury, A. (1992). The social construction of scientific concepts or the concept map as conscription device and tool for social thinking in high school science. *Science Education, 76,* 531–557.
Roth, W.-M., van Eijck, M., Reis, G., & Hsu, P-L. (2008). *Authentic science revisited: In praise of diversity, heterogeneity, hybridity*. Rotterdam: Sense.
Roth, W.-M. & Walshaw, M. (2019). Affect and emotions in mathematics education: Toward a holistic psychology of mathematics education. *Educational Studies in Mathematics, 102*, 111–125.
Silió, E. (2019, November 25). Los escolares finlandeses deciden ya cómo y qué aprenden [Finnish students already decide how and what they learn]. *El País*. Retrieved from https://elpais.com/sociedad/2019/11/22/actualidad/1574450032_618780.html.
Snow, R. E. (1992) Aptitude theory: Yesterday, today, and tomorrow. *Educational Psychologist, 27*, 5–32.
Suchman, L. (2007). *Human-machine reconfigurations: Plans and situated actions* (2nd ed.). Cambridge: Cambridge University Press.
Vygotsky, L. S. (1987). *The collected works vol. 1: Problems of general psychology*. New York: Springer.
Whitehead, A. N. (1919). *An enquiry concerning the principles of natural knowledge*. Cambridge: Cambridge University Press.
Whitehead, A. N. (1920). *The concept of nature*. Cambridge: Cambridge University Press.
Willenbrock, H. (2020). Alemannenschule Wutöschingen: Schule machen [Alemannen school in Wutöschingen: Making school]. Retrieved from https://www.brandeins.de/ magazine/ brand-eins-wirtschaftsmagazin/2020/eigensinn/alemannenschule-wutoeschingen-schule-machen?utm_source=zeit&utm_medium=parkett