Enhancing mathematics / STEM education

Inaugural lecture
Prof.dr. Birgit Pepin
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Enhancing Mathematics/STEM Education: a “resourceful” approach

Where innovation starts

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Introduction

Mr. Rector Magnificus, Ladies and Gentlemen.

I take this occasion to thank you for giving me the opportunity to describe my own research journey over the past twenty years, and how I see the way forward for working and researching in STEM education, in particular with STEM teachers in secondary and tertiary education.

STEM is the acronym for Science, Technology, Engineering and Mathematics, and it encompasses a variety of other subjects that are counted under each of these terms (e.g. aeronautical engineering; biochemistry; computer science; nanotechnology; nuclear physics). Internationally, there is a growing concern for developing and strengthening STEM education to prepare students for a scientifically and technologically advanced society, as students' mathematical and scientific "literacy" is often said to be underdeveloped. These subject areas, so it is argued, play a vital role at multiple levels of society. Some often mentioned examples: environmental issues (like nuclear power or sustainable energy) are steeped in the sciences; medical research is fuelled by the study of chemistry and biology; a country's economy revolves around mathematics, in accounting and the economy; and architecture relies on mathematics in its urban development and city planning. It seems impossible to find a part of society that does not, in some way, interact with and, to some extent, depend on these subjects. In addition, STEM related occupations are amongst the most respected, and best-paid. So, to educate a strong STEM-knowledgeable society is indispensable, and hence good STEM education is essential to our education system in the Netherlands, and internationally.

At the same time, it is clear that preparing students for an innovative society goes well beyond preparing them for science-related professions. Given that a large share of professionals contributes in some way to innovation, the new educational imperative is to equip a critical mass of workers and citizens with the skills to thrive in innovative societies (Mavareck & Kramarski, 2015). Where are these skills anchored? There is ample evidence that some of the most crucial skills are formed and developed in the STEM subjects. For example, "design-based learning (DBL)", where students gather and apply theoretical knowledge to solve design problems, not only helps students in schools to apply science concepts in secondary education, but design-based learning (and thinking) is also, and predominantly, used in economics, financial modelling and risk analysis. It has been shown that mathematical sciences are often seen as the foundation for science and engineering, and critical for the success of an advanced economy (Deloitte/Platform Wiskunde Nederland, 2014).

In summary, it can be assumed, and there is a global perception, that a workforce with a substantial proportion educated in STEM is essential to future prosperity. We know that at national as well as at European level there is a shortage of (1) students choosing, and staying in, domains of STEM in higher education; and (2) of well-qualified secondary teachers in the domains of STEM. The reasons for that are manifold, one of which is likely to be that mathematics and science teaching and learning have often been regarded as non-attractive, “dull” and “boring”, and rather fact- and procedure-driven (e.g. Brown, Brown, & Bibby, 2008). The fact remains that few secondary students are well prepared to continue their studies in mathematically, scientifically and technologically demanding courses in higher education institutions (Hulme & de Wilde, 2014). Hence, it seems important that more students are attracted to and given appropriate opportunities to engage in such demanding subjects. The question is not whether the STEM subjects are demanding and challenging - because they are; the question is whether more students are prepared, equipped and willing to face those challenges. A crucial factor to achieve this would be that more and better mathematics, technology, science and engineering teachers become available. STEM education research can help teachers and institutes to make the required shifts, to obtain insights into how to best educate students in mathematically- and scientifically-demanding courses, and to make the STEM subjects more attractive and accessible for students.

In this inaugural speech, and after this introduction, I shall first describe three selected problems in STEM education, the ones that I perceive as the most pressing, namely: (1) the transition from school to university STEM education; (2) the integration of STEM curriculum subjects; and (3) competence in/for STEM teaching. In the second and main part of my speech, I develop the argument for a “resourceful” approach. I explain why and how I consider that “re-sourcing” teachers’ work and working with STEM teachers with/on STEM resources, in particular digital resources, is not only an authentic and sensible way of working with teachers but, more importantly, it contributes to the enhancement of their knowledge in/for STEM teaching and their didactical flexibility. In the last part I shall summarise my argument and outline the implications of the suggested approach for future developments in STEM teacher education/professional development and research.

Issues in STEM education

In this part of my presentation I highlight and explain the three aforementioned problems in STEM education.

a. The transition from school to university STEM education: different classroom norms and habits of mind

> "My undergraduate years at MIT were the darkest and most traumatic periods in my life. For the first time I went to class and literally did not understand a single word or diagram. For the first time I was probably the most stupid student in a class, or felt that way. For the first time I had to miss sleep because of studying. For the first time I failed exams and got F grades. I would stare and think about my math problem sets for hours without any progress. And I was not used to not working alone and asking help from others." (anonymous respondent, 2015)

This quote indicates that even in the most prestigious institutions (such as MIT) students, who were high-achievers in the sciences in their previous schooling, get "alienated" (Williams *et al*., 2011) and have difficulties to "survive" the early years of mathematically, scientifically and technologically demanding courses (e.g. Gueudet, 2008).

When students change from upper secondary schooling to university STEM education, many things change for them (besides the change from home to university life). Leaning on the French notion of Didactic Contract (Brousseau, 1997), I have argued that the Didactic Contract changes when students transit from school to university mathematics (Pepin, 2014, with examples from the UK TransMaths project[1]):

- From (being taught by) teachers to lecturers/professors: this often means from "personal/individual attentiveness", also in terms of their subject learning, to "distant helpfulness".

[1] http://www.transmaths.org

- From lessons in classrooms (ca. 25 students) to lectures in large lecture halls: this underscores the (potential) anonymity of university education, and the fact that students are expected to become self-regulated learners.
- From school STEM/subject to university STEM/subject: in many subject areas it appears that the (epistemological) nature of the subject changes, and the subject is often not recognizable for students, from one context to the other. In other words, the STEM subject they have learnt in school does not resemble the subject they learn at university.
- From school subject learning to university STEM learning: as the epistemological nature of the subject changes, so does the learning. There is evidence (e.g. in mathematics; see Tall, 2008) that at school students learn mainly procedural skills, whereas in university STEM courses they are expected to clearly state their assumptions, theoretical frameworks and definitions; they have to design and construct, decide what and how to measure, observe and sample, select tools to measure and collect data; they have to evaluate their design(s); and they have to reason and provide evidence, also with rigorous proof.
- From textbooks to course materials: whereas in school typically one textbook is used by students, and this contains the curricular requirements of the course, at university students are expected to study from a larger variety of resources, including lecture notes (provided by the lecturer), several textbooks (for particular sub-domains) and students' own notes (from lectures and tutorials), amongst others.

These changes often lead to problems for students who have developed, and feel safe with, particular routines, learning practices and habits of mind. To give an example, and here I exaggerate in order to make my point clear: in school students often get accustomed to the "reproduction" of knowledge, they are often provided with "recipes" (for solving tasks, etc.). However, when they enter university, this is much less the case, in particular in STEM courses; what they need here are predominantly problem-solving and design skills.

Let's look into a traditional (mathematics) classroom, or lecture: often a task/worked example is used by the teacher/lecturer to introduce a new concept or technique and, subsequently, students practice the technique using similar tasks/exercises. This type of teaching is often referred to as 'Triple X' teaching: exposition, examples, exercises (e.g. Evans & Swan, 2014), a common approach in particular in upper secondary mathematics education. Subsequently, students (who were successful at upper secondary science/mathematics education) arrive at university and expect the same “recipe-like” approaches in their university courses. After all, there lies a certainty in following similar tasks, in the sense that one can study and learn all “recipes” to be prepared for the examinations. Also for the teacher this is a “safe” method, in the sense that the teacher can prepare all tasks in advance, so that all students solve each task using the same method, and be safe in the knowledge that he/she has covered the prescribed curriculum. However, the situation is quite different if students are encouraged to employ different approaches to solve the same non-routine task, and the teacher’s role becomes clearly more demanding (as students may identify and use unanticipated solution methods, which may result in unforeseen difficulties).

The research literature (e.g. Pierce, Stacey, Wander, & Ball, 2011) contends that there are clear benefits to learning with understanding, comparing and discussing multiple solutions and approaches to a problem. One of the most beneficial approaches is for students to share “emerging” strategies within a whole class discussion (after having tackled the problem in groups or individually), and learning to critique and discuss alternative problem-solving strategies (e.g. Evans & Swan, 2014). Instead of wishing for “recipes” and more “worked examples” (how to solve a problem), this practice, as an example, is likely to foster students’ problem-solving and design skills, which is what is needed in higher STEM education, and more importantly in an innovative society.

This takes us to the next issue: how to organize the STEM curriculum subjects.

b. The integration of STEM curriculum subjects

Imagine the situation of a student in upper secondary education, going from a mathematics lesson of “functions and graphs” to a science lesson where they conduct an experiment and subsequently have to devise representations for structuring data and patterns of observations (i.e. draw graphs). Often, students do not recognize the same concept (in this case the concepts of functions and graphs) in two different contexts. As a result they “store” what they learnt separately in the mathematics and in the science classroom, without making connections from one to the other, as separate pieces of knowledge. An integrated STEM approach is said to help address this problem.

Whilst many new initiatives in the STEM field address the STEM disciplines separately, there is an increasing number of advocates for connecting the subjects, and there is a greater emphasis on multidisciplinarity (e.g. Meijers & den Brok, 2013). It is argued that teaching STEM subjects in a more integrated way makes the fields more relevant to students, which may ultimately increase their motivation and achievement. However, it is not at all clear what would be, for example, the *nature and scope* of such integration, and indeed its *implementation*. Many questions are still unanswered, such as: which subjects should be connected (all or selected ones and, if selected, which ones; which disciplines are dominant), which disciplinary knowledge can be learnt in an integrated STEM situation (and which is best learnt separately), which instructional approaches/designs (e.g. problem-based learning and engineering design) are likely to enhance/support connection-making between and among disciplines (and how can this be measured), and what kinds of student support, and resources, are needed for particular instructional designs, to name but a few. When looking across research and outcomes of studies from integrated STEM initiatives, it appears that “connecting STEM concepts and practices holds promise for increasing student learning” (National Academy of Sciences, 2014, p.2).

However, there are also voices of caution. STEM (and general) education research shows, for example, that students do not spontaneously connect and transfer concepts across different subjects, representations and materials, but they need considerable and explicit support to build knowledge and skills within and across disciplines (ibid.). Connecting concepts and ideas across disciplines also requires students to have a good understanding of the relevant ideas in the individual disciplines (before these can be connected/transferred to other domains), and one must not inadvertently undermine student learning in the individual subjects. Hence, it may be wise to take a measured, considerate and strategic approach to integration here, one that accounts for the potential trade-offs, the affordances and constraints, in terms of cognition and learning environments.

While these issues of nature and scope, and implementation of interdisciplinary teaching of STEM have not been resolved, students experience the subjects separately, struggle to connect the “knowledge pieces” and lose interest in the subject, at least at the level of secondary schooling. This leads us to the next issue: competence in/for STEM teaching.

c. Competence in/for STEM teaching

It is clear that the expertise of the educators is a key factor in determining whether STEM education can be enhanced, and that this enhancement would produce positive outcomes for students (in whichever way one defines outcomes here). It is often assumed that teachers’ content knowledge in the subjects being taught is limited (and hence teachers are being encouraged to take more subject courses). My claim is that it is not the subject knowledge per se. I see a lot of students in STEM teacher education, who have appropriate subject knowledge in their discipline (in particular for teaching in secondary schools). However, their "*Bèta-Didactical Knowledge*" (BDK) and "*Bèta-Didactical Flexibility*" (BDF), for example, the teacher's flexibility to be able to see the subject content from a different angle or to integrate STEM subject teaching, are often very weak.

Bèta-Didactical Knowledge (which includes the typically Dutch term bèta-sciences, i.e. the natural sciences and mathematics) can be aligned with *Pedagogical Content Knowledge (PCK*) for the Bèta subjects (see Shulman (1986) for the notion of PCK in general; Loewenberg-Ball and team (2008) for PCK in mathematics education; van Driel and colleagues (e.g. Van Driel & Berry, 2012; Van Driel, Verloop, & De Vos, 1998) for PCK in science education. *Bèta-Didactical Knowledge* can be broadly defined as the knowledge about teaching and learning of the STEM subjects, which includes knowing what to do with students to help them understand STEM concepts, which (curriculum) materials there are to help the teacher, what students are already likely to know and what would be difficult for students, what are the misconceptions and how to address them, and how best to evaluate what students have learnt. In short, the knowledge that may distinguish a teacher from a subject matter specialist.

Returning to my focus here: my claim is that our student teachers typically do not need more content knowledge, but rather more subject-specific didactical, or bèta-didactical knowledge and flexibility.

After identifying and explaining, from my point-of-view and with the support of selected literature, what I see as important issues in STEM education, I now turn to the main part of my lecture: how to address these issues in a "resourceful" way.

A "resourceful" approach: teachers working with resources

In this part of my presentation I shall (1) provide a definition of what I mean by "resources"; (2) explain the processes of teachers' work with resources; (3) focus on the role of particular resources, i.e. the textbook; (4) and subsequently on the role of digital resources (e.g. e-textbooks); (5) address issues of quality and coherence; and (6) provide examples from selected studies.

Definition

In our work in mathematics education (that is my work with my French colleagues Luc Trouche and Ghislaine Gueudet), we have anchored our understandings of a *resource* in the work of Adler (2000), who usefully explains that

> "It is possible to think about a resource as the verb "re-source", to source again or differently. This term is provocative. The purpose is to draw attention to resources and their use, to question taken-for-granted meanings." (p.2)

Hence, a resource can be of material (e.g. texts) or human (e.g. colleagues) nature. In most of our work we lean on a definition by Pepin and Gueudet (2014) of mathematics curriculum resources as:

> "... all the resources that are developed and used by teachers and pupils in their interaction with mathematics in/for teaching and learning, inside and outside the classroom. Curriculum resources would thus include the following:
>
> - text resources, such as textbooks, teacher curricular guidelines, websites, student sheets, and syllabi;
> - other material resources, such as manipulatives and calculators;
> - ICT-based resources, such as computer software." (p. 132)

Teachers' work with resources: a way to develop bèta-didactical knowledge and flexibility

We see teachers' work with resources as a truly interactive process between the teacher and the resource/s. When working with the resources, adapting and appropriating them, the teacher enhances his/her *knowledge* and his/her *design capacity*.

> "Resources are essential for [mathematics] teachers, and teachers use different kinds of resources, which shape the [mathematical] content presented to, and used by, pupils in their [mathematics] learning. Moreover, when appropriating resources, teachers adapt them to their needs and customs. This process of '' and interpretation of resources then continues 'in use'– hence transformation is seen here as 'design-in-use'." (Pepin, Gueudet & Trouche, 2013, p.1)

Hence, it is recognized that, when teachers interact with *curriculum resources* (including textbooks), they develop knowledge: individually when preparing their lessons and collectively in professional development sessions with their colleagues (e.g. Gueudet, Pepin, & Trouche, 2012; Ruthven, Laborde, Leach, & Tiberghien, 2009). Teachers' interaction with (different) resources has been theorized in different ways (e.g. Pepin, *et al*., 2013). What is evident from these theoretical frameworks (e.g. Gueudet *et al*., 2012; Gueudet & Trouche 2009) is that it is a participatory (two-way) process, in which teachers and resources interact with and influence each other. Making sense of and using these resources to design and enact instruction places a demand on teachers' *pedagogical design capacity* (PDC) (Brown, 2009) - a teacher's ability to effectively utilize and appropriate existing curricular resources to (re-)design instruction. At the same time, a teacher's pedagogical design capacity must be dependent, to some extent, on the particular resource being used (each resource has different affordances and constraints), and on the ways of working, individually or collectively, with the resource (Gueudet, Pepin & Trouche, 2013).

The role of textbooks

In terms of curriculum resources, over decades textbooks have been said to be the main curriculum resources used in STEM classrooms (Valverde *et al*., 2002), by teachers and by pupils. Valverde *et al.* (ibid.) claim that textbooks "are the print resources most consistently used by teachers and their students in the course of their joint work." (p.viii).

In my own work in the UK (and following my PhD on mathematics teachers' work/didactic practices in England, France and Germany, see Pepin 1998), my colleague Linda Haggarty and I have investigated mathematics textbooks in lower secondary classrooms in England, France and Germany, and mathematics teachers' use of those books (Pepin & Haggarty, 2001). At that time the textbook was a crucial ingredient of every mathematics lesson (in those countries), and this is probably still the case in many countries' classrooms. It is a fact, also today, that curriculum resources are a vital ingredient for every teacher's work: in terms of lesson preparation, that is for instruction, in and during instruction in class, and for assessment.

Numerous studies have investigated the use of textbook by teachers, and many have highlighted the textbook's role for offering opportunities for students to learn. Indeed, teachers' decisions about the selection of content and teaching strategies is often directly related to the textbooks they use, and hence textbooks are regarded as influencing, and sometimes determining, the degree of students' opportunities to learn (e.g. Haggarty & Pepin, 2002; Törnroos, 2005).

Digital resources

Today's curriculum resources (including textbooks) look very different to resources of even just a decade ago. Internationally, a new wave of curriculum materials, in particular e-textbooks, is providing teachers with more than a digitized version of the hard copy textbook plus a few digital applications to support the text. Recently, publishers have invested in videos, interactive applets and personalized assessment designed to support teachers in their enactment of the curriculum, and to engage students more deeply in their learning. More recently, Open Educational Resources (OERs) have received considerable attention. The Organisation for Economic Co-operation and Development (OECD, 2007) defines OERs as

> "digitized materials offered freely and openly for educators, students, and self-learners to use and reuse for teaching, learning, and research. OER includes learning content, software tools to develop, use, and distribute content, and implementation resources such as open licenses". (p. 10)

Whilst digital resources (including OERs, e-textbooks) have received considerable attention, relatively little research, however, has been conducted to examine their quality, the ways they are used by teachers (and students) and how the nature of digital resources, in particular e-textbooks, influences teacher agency (as compared to traditional books). It is clear that the digital nature of curriculum resources affords numerous possibilities for interaction, individually and collectively:

- between teachers and their teacher colleagues: digital means provide opportunities for teachers to prepare and discuss lessons together, in particular if the tools are part of the e-textbook.
- between teachers and pupils: digital tools may offer tools/interfaces for teacher/pupil communication, for example for setting and assessing individualized homework (for pupils with special educational needs).
- between teachers and parents: digital means provide opportunities, and interfaces, for teachers and parents to communicate (e.g. about the progress of their pupils, to encourage further support in particular subject areas).
- between teachers and textbook authors: if the e-textbook allows teachers to change the content (e.g. teachers can propose suitable tasks, or indeed tools, for a particular content/learning sequence), these suggested changes can be approved by the e-textbook author group and subsequently included in the textbook; hence teachers become “co-authors”, and the authority of the text changes. (Pepin, Gueudet, Yerushalmy, Chazan & Trouche, 2015).

Issues of quality and coherence

Comparing traditional and digital/e-textbooks, it has become less clear what “quality” and “coherence” actually mean for digital resources, and how teachers can evaluate these in and for their instruction. At a time when teachers become part of the (co-) authorship of e-textbooks, who defines what quality/coherence actually is? Next, I argue that with the introduction of digital interactive resources to an e-textbook, the notion of “quality” and “coherence” of a textbook may need to be re-conceptualized. I explain this in the following.

In recent studies (e.g. Pepin *et al.*, 2015) we have investigated the quality and coherence of two commonly used French textbooks: one was a traditional textbook (authored by authorities/inspectors and known teacher educators/textbook authors in the field), and the other a digital textbook (Sésamath) developed by a group of teachers, the Sésamath association. In addition, we have followed and studied the “production” of a grade 10 Sésamath e-textbook (Gueudet, Pepin, Sabra & Trouche, 2015). These studies highlighted the changing nature of authorship: on the one hand the traditional “expert” authorship, which guaranteed a “didactic” (albeit “static”) quality of the textbook; on the other a large teacher group authorship, where a particular group was assigned as gatekeepers. At the same time, "ordinary" classroom teachers trialed the content (of the e-textbook) and wrote in to the author group, which led to subsequent changes of the book's content – we called this a "dynamic" quality of the Sésamath e-textbook.

Subsequently, based on the examination of three different types of e-textbooks (including Sésamath), we have proposed three types of coherence:

- *Initial design coherence* - in terms of coordinating the authors' intentions shaping the choice and design of content;
- *Product coherence* – in terms of and linked to the technological tools used/available (e.g. graphing tools; hyperlinks) for representing, designing and working with the subject matter; and
- *Coherence-in-use* – referring to how teachers can (and may be advised to) use the book (see Pepin *et al.*, 2015).

Moreover, we defined an e-textbook as an evolving structured set of digital resources, dedicated to teaching (and learning), initially designed by different types of authors, but open to re-design by teachers, both individually and collectively (ibid.).

Examples from selected studies

The **Sésamath e-textbook** (see **http://www.sesamath.net/**), which is freely available online, is an interesting example. In 2001 the Sésamath association started to produce "mathematics [resources] for all" (see Fig. 1). The *mode of design* of the Sésamath textbooks (Sabra & Trouche, 2011) typically involved a large number of actors. For example, approximately one hundred teachers have contributed to each textbook produced, in a *collaborative* and *iterative* way: as 'authors of content', 'designers of didactical scenarios', 'testers' or 'experimenters' in classes. Over the years the textbook models have become more and more sophisticated. The early model was a hard copy accompanied by separate animations (e.g. Mathenpoche exercises: practice and drill exercises). The subsequent model was a flexible and dynamic digital textbook, which teachers could modify and change according to their needs. Finally, the third and most recent model of the Sésamath textbook is a flexible and dynamic digital textbook, which offers a "laboratory" (*LaboMEP*: *Laboratory for Mathenpoche*) for collaboratively adjusting the textbook to the needs and projects of the community (school, team of teachers). *LaboMEP* allows teachers to develop and share their lessons, but also to differentiate their teaching according to student [test] results (with a particular resource – *Pepite* – that has been developed through the collaboration of Sésamath with researchers – see Pepin *et al.*, 2015).

Figure 1

Webpage of Sésamath resources

In terms of **lessons learned from international projects**, I report on the examples from three European projects we have conducted in Norway (PRIMAS, MaSciL, FASMED) and my work in China/Shanghai.

In the **European projects** we have researched mathematics and science teachers working collaboratively with digital (and traditional) resources (e.g. Sikko, Lyndved, & Pepin, 2012). Teachers were provided with specifically developed mathematics and science tasks, and/or technology tools, and/or professional development modules, and teachers transformed and appropriated these resources to fit their teaching. A particular aspect of two of these projects (PRIMAS, MaSciL) was that it was expected that those teachers working with the university educators would, in turn, become instructional leaders (or ‘multipliers’), that is work with colleagues in their schools in terms of professional development.

From this work it became clear that two aspects were crucial: firstly, the digital resources needed to offer the didactical flexibility that teachers could adjust them for their teaching, and at the same time propose innovative and 'feasible' ideas/designs for their lessons; secondly, teachers needed time and support (also from their principals) to work effectively with these resources. In terms of collective work, interestingly, teachers (said that they) were not used to working together (in their schools), but emphasized that this is needed for enhancing their knowledge and design capacities.

Figure 2

PRIMAS teachers working with resources in a professional development session

In the Shanghai project, my experiences were very different in terms of collective work. In China, there is a culture of teachers working together in "Teaching Research Groups" (TRG) (e.g. Pepin, Xu, Trouche, & Wang, submitted). These TRGs discuss and work on particular lessons (of their grade), in the culture of "Lesson Study" and/or "Open Lesson", and every teacher is obliged to participate. The research in Shanghai revealed how effective teachers' collaborative work can be. For example, working together on the content of one particular lesson, improving particular aspects through design and re-design using subject-didactical considerations, discussing the advantages and disadvantages of particular resources and tools were regular practices in the TRGs. These practices reflected an "openness" (to be criticized by and to criticize peers), a clear focus (e.g. particular resource, particular aspects of a lesson) and depth of "practical" and didactical analysis that I have not often experienced.

In the next section I will summarize my line of argumentation under four points, and explain what I mean by innovative “resourceful” approach, leading to selected recommendations for STEM teacher education and research.

Main arguments and the way ahead

"If you want to change something, you have to understand it, and if you want to understand something, you have to change it" (adage in Gravemeijer & Cobb, 2006).

First, in recent decades many changes and reforms have entered and influenced the STEM classroom (and STEM education), and it is timely to invest in teacher education (Beijaard, Meijer, & Verloop, 2004), in particular in the professional development of STEM teachers. My argument is that professional development in particular should be focusing on "resources". When I suggest "re-sourcing teachers' work", I mean looking again, with a fresh view, at STEM teachers' "sources" for (inspiration for) their work, working with teachers on "resources". As teachers work with resources all the time, in and out of class, focusing on resources and organizing professional development with and around (particular) resources seems to me to be the most accessible and sensible way of working with teachers: resources provide a window into teachers' work, and a practical and authentic way of working with them. The resource, whether it is a textbook, a particular task, or a particular software or applet, is always part of the teaching/learning process and the learning environment.

Several documents and reports have outlined their vision (e.g. Platform Wiskunde Nederland, 2015) indicating that STEM teachers need to undergo a more rigorous university education characterized by the enhancement of teachers' bèta-didactical knowledge and design capacity (De Putter-Smits, 2012) – in my view crucial elements of the education of secondary teachers.

Second, I (and others) have argued that the work with resources involves a dynamic teacher-resource relationship whereby both teacher and resource influence each other. These interactions are complex: the teacher working with the resource changes the resource and, at the same time, the affordances and constraints of the resource influence/change the teacher. This process of mutual adaptation is conducive to the development of teachers' design capacity (Brown, 2009). The emphasis is on the active and interactive nature of teachers' work with resources. Teachers are (or become) active designers and users of resources (and not simply "transmitters") of what is prescribed by others, as they interpret and participate with the resource (Remillard, 2005).

Reflecting on our work with mathematics and science teachers over the past 25 years, we can hypothesize that with the enormous amount of digital curriculum resources freely available on the Internet, e-curriculum resources have become as important as, or perhaps even more important than, the single textbook for teachers in their lesson preparation and instruction. Typically, textbook publishers now provide plenty of teaching materials online (besides hard copies), ranging from tailor-made worksheets to questions databank software (also for assessment); from self-developed teaching software to electronic textbooks. These e-textbooks are often supplied with interactive layouts and multi-functional features aimed at supporting teachers in/for their classroom instruction. However, this abundance of digital curriculum resources begs the question of choice by teachers: which criteria do teachers apply and whether they combine particular resources. In short, it would be interesting, and necessary, to know why and how STEM teachers use e-curriculum resources. Based on our research, the change in the nature of resources (from text to digital curriculum resources) is likely to imply a change in teachers' resource systems and, moreover, in their work and activities. Understanding the modifications and transformations resulting from these changes means, so we argue, to understand how a teacher's integration and appropriation of the e-textbook/digital curriculum resource into his/her resource system modifies this system, and there are associated implications for teachers' work and professional development.

Third, I argue that particular resources, namely digital resources (such as e-textbooks), open up new possibilities for working with teachers: there is an abundance of digital resources on the web, and STEM teachers often do not know how to choose or modify those available resources. These interactive digital resources offer design (and re-design) opportunities for teachers as they become part of their development. Moreover, in the process it is likely that they have the potential to change the traditional relationships between teacher and textbook (as well as between student and textbook, or between students and teachers), as we have seen that e-textbooks offer new possibilities for teacher to become "co-authors" (see Sésamath).

Research on this third aspect would include: analyses of the quality characteristics of "useful" digital resources and of their potential for creative use in/for STEM teaching; investigations of STEM teachers' resource systems with respect to STEM teachers’ competence; and examination/s of “effective overlap” of teachers’ and students’ resource systems with respect to mediation and scaffolding capacities (also in higher education STEM teaching and learning)

Fourth, I have argued that the research and development work with (digital) resources should happen in teams, communities and networks, that is in collectives which I name Bèta-Didactical Design Communities. These are communities where not only STEM teachers, student teachers and university teacher educators work together on/with digital resources, but also university subject specialists and STEM university students. On a minor note, in the context of STEM there are some interesting resemblances between technical and “didactical” engineering processes.

Here I would envisage research studies that investigate the conditions (or “constellations”) under which these design communities are actually effective. For example, would “mixed” design communities (i.e. mathematics, physics and technology colleagues working together focusing on the same resource appropriated for different subject teaching) help the integration of the STEM subjects? The notion of “effectiveness” might also be interpreted in different ways: effective in enhancing teachers’ design capacity, for example, or in engaging more students in the processes of bèta-didactical engineering and, in turn, attracting more students to STEM studies and teacher education.

Moreover, design communities may also consist of teacher educators. We have to ask which kind of education, skills and resources are necessary, and helpful, when learning to become a teacher in teacher education. How can we professionally develop instructional leaders, and what is the role of resources in this process?

These four components can be regarded as anchor points for my overall message: the **advancement of STEM education requires “re-sourcing”**!

Epilogue

At the end of my speech, I would like to express some words of appreciation and thanks.

First, I like to thank the Executive Board of TU/e, in particular former Rector Hans van Duijn, for appointing me to this chair in Math/STEM education. I am equally grateful to former Dean of the Eindhoven School of Education, Douwe Beijaard, for his initiative and support in making this appointment possible. Douwe and Perry (den Brok), our recently appointed dean of EsoE: you have both been very welcoming and helpful in enabling me to make my transition, coming from Trondheim to this new working environment in Eindhoven, somewhat easier than I might have feared. My stay at ESoE is still relatively recent but my first experiences have been stimulating and I am looking forward to years of fruitful and pleasant cooperation. I would like to extend the same positive wishes to all other colleagues at ESoE in particular and TU/e at large. I hope to contribute to an even stronger STEM profile of ESoE and also to build solid bridges between ESoE and the science and engineering departments of TU/e in addressing the joint challenge of educating more and better STEM teachers.

At this event, I would also like to say a few words of thanks to colleagues that have fulfilled an inspiring and supportive role during my career (or are still doing so). Actually, over the course of my academic work in various European countries, many persons deserve to be mentioned, but let me here focus on just a few of them:
My main mentors during my academic upbringing in England: Bob Moon (Open University) and Linda Haggerty (University of Reading).
My later colleagues Gary Thomas (Oxford Brooks University, now University of Birmingham) and Julian Williams (University of Manchester), who helped me to get ready for my professorship in Norway. In Norway, my colleagues at HiST where I worked for six years, who not only taught me Norwegian, but also how stimulating a new environment can be.
Special words of thanks are also in place for some other dear international colleagues with whom I have had the pleasure to work and collaborate: Kenneth Ruthven (to whom I am especially grateful for his speech during the symposium

today), and my passionate French co-workers Ghislaine Gueudet (Brest) and Luc Trouche (Lyon).

Last but not least, in Dutch academic ceremonies like an oratio, it seems permitted to express words of thanks to one’s private circle. Given this opportunity, I like to follow this habit. Without mentioning each and every one of you all in name today, I would like to express my feelings of gratitude to all of my family relatives and dear friends, some present today, others abroad at this moment. Thank you all for your loyalty, love and support.

Ik heb gezegd.

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Curriculum Vitae

Prof.dr. Birgit Pepin was appointed full-time professor of Mathematics/STEM Education at the Eindhoven School of Education (ESoE) on January 1, 2015.

Birgit Pepin received her Master's degree in physics/meteorology from Christian-Albrecht-University Kiel (Germany) in 1982 and, after some years of child raising, continued her education at the University of Oxford (UK), where she graduated as a mathematics teacher for secondary education. After working as a mathematics teacher in local secondary schools, she embarked on a PhD in mathematics education and received her PhD degree from the University of Reading (UK) in 1998. The PhD thesis compared the didactic practices of mathematics teachers in schools in England, France and Germany. Subsequently, she took up a post-doctoral position as research fellow at the Open University, followed by positions as associate professor at Oxford Brookes University and the University of Manchester. In 2009 she was appointed professor of mathematics education in Trondheim (Norway). Her current research interests and expertise include the education (and professional development) of mathematics/STEM teachers, international and comparative studies in mathematics education, and mathematics/STEM teaching and learning in higher education. In particular, she has investigated mathematics teacher interaction with "resources".

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