Sprong-STEM - Recommendations

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Abstract
This chapter elaborates on four challenges related to the specific character of Science, Technology, Engineering and Mathematics (STEM) education in primary education in The Netherlands. Before focusing on these challenges, we sketch out an overview indicating the importance of STEM-education. From this partly historical analysis we focus on the following challenges: (1) assessing learning outcomes in STEM education, (2) the relation between mathematics and other STEM domains, 3) data literacy and maker education in STEM education and (4) the critical role of teachers' content knowledge in STEM teaching. With respect to these challenges we describe both theoretical as well as practical questions and demands that emerged from professional learning networks. Classroom examples further illustrate these challenges. The chapter concludes with recommendations for further research and curriculum development in STEM education.

1. STEM Education in the Netherlands

1.1 Importance of STEM education
Understanding complex present-day problems like climate change or migration touch upon all four domains in STEM. For example, climate change is explained using sciences like chemistry and physics, while mathematics helps modelling the situation. Technology and engineering are required to deter climate change, for example, by designing and manufacturing cars and airplanes that run on hydrogen. Science, Technology, Engineering and Mathematics (STEM) education are considered essential to solving these challenges and therefore important to Dutch society (Bom, Koopman, & Bijaard, 2019; Gresnigt, 2018; Rohaan, 2009). The increasing shortage of workers in the STEM fields has a negative impact on the Dutch economy. In addition, technologization is rapidly changing the labor market. More and more jobs require scientific, mathematical and technological competencies (Kirschner & Stoyanov, 2020; Hoogland, 2023; Gal, 2024a). Moreover, rapid scientific and technological advancements raise social and ethical issues. Understanding mathematics, science and technological developments, their possibilities, limits, and the ethical and democratic dilemmas that they bring forth is crucial for every citizen in today's society (Laugksch, 1999; Gravemeijer, Stephan, Julie, Lin, & Ohtani, 2017; Guérin, 2018). Primary education should therefore acquaint children from early on with STEM, develop their STEM content knowledge, skills, and attitudes, and stimulate them to continue learning about STEM (Post, 2019).

1.2 Historical perspective
Over the past decades, there have been repeated calls in the Netherlands to increase attention to STEM in primary education. In Dutch primary education the STEM areas are often referred to as Science and Technology (S&T) education. Mathematics has its own curriculum and learning goals. Although repeated calls have been made to connect Mathematics and S&T, these subjects are usually taught separately in primary classrooms. Until recently, the S&T curriculum mainly emphasized life science and physical science. Technology constituted only a small part of the curriculum. However, due to a growing focus on technology in society, technology and engineering is more explicitly incorporated into science, resulting in a more balanced S&T (E) curriculum (Rohaan, 2009). This also means increased attention to engineering, as engineering knowledge and skills are integral part of technology education (Post, 2019).

Initially, the S&T(E) curriculum focused on developing content knowledge and skills. A vision report published in 2005 introduced a new dimension: stimulating S&T(E) attitudes by nurturing children's inquiring minds (Post, 2019). Children with a positive attitude towards S&T(E) are more inclined to pursue a career in STEM fields (Bom, Koopman, & Bijaard, 2019). Therefore, it is important that teachers stimulate the development of a positive attitude (Van Aalderen-Smeets & Walma van der Molen, 2013). Stimulating this attitude towards S&T, teachers are encouraged to structure their science lessons according to the inquiry learning cycle and their technology lessons according to the design learning cycle, stimulating students to think and work as scientists and engineers (Bom, Koopman, & Bijaard, 2019; Rohaan, 2009).

Although many (prospective) teachers enrolled in S&T(E) courses, the number of schools implementing design and inquiry learning remained limited. According to studies conducted at that time, attention to S&T(E) education actually decreased (Kneepkens, Van der Schoot, & Hemker, 2011). An Advisory Committee on Science and Technology Education was established to advise on integrating S&T(E) into the primary school curriculum. By spring 2013, the committee issued its recommendations. One suggestion was to have the national institute for curriculum development in the Netherlands, SLO, develop the S&T(E) curriculum and exemplary learning materials for primary education. Additionally, the committee proposed integrating S&T(E) with other subjects, particularly mathematics and language (Post, 2019).

A national S&T(E) curriculum was published in 2018 and operates on the premise that S&T(E) is a lens through which to view and approach the world. By posing questions, solving problems, and using imagination, children learn about the world, develop their research and engineering skills, and develop their scientific attitude. Despite offering practical insights, the implementation of the S&T(E) curriculum has fallen short in practice (Post, 2019). A recent study by Djoyoadhiningrat-Hol and Klein Tank (2023) indicates that less time is being allocated to S&T(E), even though most schools aspire to implement the S&T(E) curriculum and work on it structurally.

1.3 Connecting S&T(E) and mathematics

Although mathematics has its own developmental history, curriculum and attainment goals in Dutch education (Van den Heuvel-Panhuizen, 2020), schools as well as experts in the field of mathematics teaching express a desire to connect S&T(E) with mathematics (Van der Aalsvoort, Van der Zee, & De Wit, 2020). Some of the major reasons for this are the increasing role of mathematics in other fields and the approach to primary mathematics education in the Netherlands called Realistic Mathematics Education (RME). RME takes meaningful mathematical situations as a starting point and supports students in a process of mathematizing, allowing children to start learning from their intuitive mathematical notions and informal procedures. Under the careful guidance of a teacher, children rediscover and reconstruct mathematics (Oonk, Keijzer, & Zanten, 2020). This socio-constructivist approach to mathematics learning lends itself to connecting with other subjects of the curriculum and curriculum integration. Thus, mathematics need not be taught only as a separate subject.

Some of research and engineering skills, like modelling and representing are part of the S&T(E) curriculum and also match aspects of the mathematics curriculum. This however is not enough for teachers to integrate mathematics with other ST(E)M subjects. Experts agree that primary school teachers lack subject matter knowledge, pedagogical content knowledge, and self-efficacy to teach S&T(E) and to connect it in meaningful ways to mathematics (Djoyoadhiningrat-Hol & Klein Tank, 2023; Hotze & Keijzer, 2017; Bakker, Keijzer, & Hotze, 2023). This aligns with various national and international research studies which indicate that proper curriculum integration requires far reaching expertise from teachers (Gresnigt, 2018; Van der Aalsvoort, Van der Zee, & De Wit, 2020) and studies which indicate a general lack of knowledge, skills, and confidence among primary school teachers of S&T(E) (Bom, Koopman, & Bijaard, 2019; Davis, Petish, & Smithey, 2006; Post, 2019).

1.4 Professional Learning Networks

As science education is often seen as relatively new and innovative in Dutch schools, experienced teachers tend to rely on professional learning networks. Often these networks began with teachers who completed a professionalization trajectory in science education, felt the need to implement a science curriculum in their schools and wanted to learn from each other. The examples of practice in this chapter come from such professional learning networks (PLNs). They consist of teachers, expert teachers in one of the STEM domains, researchers, and teacher educators. These networks, for example, support teachers to experience the complexity of inquiry- and design-based learning, and identify the gaps between such learning and the textbooks they use. Participants learn within their PLN, but also share findings with colleagues who do not participate in the PLN. This facilitates knowledge sharing between STEM experts and teachers, within and beyond the PLNs. For example, classroom observation instruments and tools for inquiry and design-based teaching skills are shared (Van Graft & Klein Tank, 2018).

1.5 Recurring and new challenges

The brief history of STEM in Dutch primary education reveals several recurring challenges. The first is ensuring that teachers possess sufficient understanding of S&T(E) to deliver high-quality education. As mentioned, primary school teachers usually lack the knowledge, skills and attitudes for teaching STEM. The second issue concerns connecting S&T(E) and mathematics. Mathematics is often taught separately from S&T(E). In fact, experts indicate that the increased attention on mathematics in recent years has replaced attention to S&T(E). Given the possibilities to connect and even integrate mathematics with STEM, this is a highly undesirable situation. The question is, therefore, how mathematics and S&T(E) can be connected in educational practice in meaningful and feasible ways. These issues remain unresolved and are therefore also described below as challenges.

Another demanding current issue concerns the new learning goals. In 2022, the Ministry of Education, Culture and Science commissioned the Institute for Curriculum Development (SLO) to update all attainment goals for primary and lower secondary education. The objective was to align the goals with societal developments and to establish a more coherent curriculum. To keep the curriculum up-to-date, new attainment goals were formulated for two new domains: digital literacy and citizenship education. The goals in both these domains exhibit significant overlaps with the updated attainment goals for mathematics and S&T(E). The plan is for all learning goals to be developed by 2024, followed by a 12 to 18 month period of implementing and testing their usability in practice. The question now confronting STEM educators is: How can these goals be meaningfully interwoven into the S&T(E) and mathematics curriculum?

Following the partly historical analysis in section 1, in the next sections, we focus on four challenges: (1) assessing learning outcomes, (2) the relation between mathematics and the other STEM domains, (3) Maker literacy and data literacy in STEM education and (4) the critical role of teachers' content knowledge in STEM teaching.
In the SPRONG-STEM project, funded by the National Coordinating Institute for Education Research (NRO), we addressed three of these challenges by setting up local and national professional learning networks (PLNs). Below we describe the theoretical considerations as well as practical implications and issues in classrooms that emerged from these professional learning networks.

2. Assessing learning outcomes

2.1 Introduction

In S&T(E) education students develop new knowledge and skills (inquiry and engineering), and work on attitudinal aspects simultaneously. With increased implementation of inquiry and engineering in science education, teachers feel the need to assess these aspects of learning. We will describe here the different types of assessments, and show how teachers work on determining goals and following learning outcomes in classroom settings.

2.2 The challenge of assessing S&T(E)

In a typical S&T activity, students are stimulated to use their curiosity and think critically. They gain new insights through research or working on a design project, learn to pose questions, make a research plan, collect evidence, compare results, and draw conclusions. The role of these process skills in developing of a thorough understanding of phenomena is crucial (Harlen, 1999). It is therefore essential to assess these science and engineering process skills.
In The Netherlands there is no national curriculum for S&T in primary education. Nevertheless, schools and teachers are obliged to work on national key learning objectives. For example, one key learning objective for S&T is: 'students learn to do research on materials and physical phenomena, such as light, sound, electricity, force, magnetism and temperature' (SLO, 2006). The national institute for curriculum development in the Netherlands further elaborates these key learning objectives for different grade levels in primary education with respect to both knowledge and skills.
Teachers in the Netherlands find out students' learning outcomes with respect to content knowledge through a test or quiz at the end of each theme in most Dutch textbooks. However, assessments for science process skills are generally not included in these textbooks. A possible reason may be the complexity of skills involved in learning design and inquiry (Table 1).
Skills involved in design are broad (Crismond & Adams, 2012). These skills are therefore difficult to assess. The same is true of inquiry skills. Pedastre et al (2015) developed an enhanced framework showing all aspects of inquiry-based teaching and learning.

Table 1. Skills involved in inquiry and design in primary education

Inquiry skills	Design skills

Identifying investigable questions	Problem exploration
Designing investigations	Generating ideas, formulate design requirements
Obtaining evidence	Create a working prototype
Interpreting evidence with respect to research question	Testing and optimization
Communication the results of the investigation process	Presenting

The complexity of inquiry- and design-based learning means that teachers generally find it difficult to assess learning outcomes with respect to these skills. Moreover, these skills cannot be isolated from the content or subject matter of science and engineering.
Teachers can choose between a formative way of assessment or a more summative way. S&T-education might be particularly well-suited for formative assessment as this will give teachers information about students' development with respect to skills and conceptual understanding, and possible next steps in learning. Formative assessment can be done by observing students, questioning, or asking students to communicate their thinking via drawing, writing or concept mapping. Banchi and Bell (2008) share an example of formative assessment in which teachers follow learning outcomes by having students work in lab notebooks and giving them feedback in their notebooks during their research project. Students can thus use the teacher's feedback to adjust their research plan or look at the results in more detail, thus producing a better outcome of the project.
For a summative assessment, teachers may design special assessments to elicit students' skills at the end of a lesson period. One possibility is a performance assessment. A performance assessment consists of three components: a task, a response prompt and a scoring rubric (Kruit, Oostdam, Van den Berg, & Schuitema, 2018). The response prompt may be verbal, and require immediate observation and scoring. It may also be written, using a worksheet or notebook.
In the following section, we present examples of primary school teachers working in PLNs to improve science education and assessment of learning outcomes.

2.5 Classroom examples of assessing learning outcomes
In S&T(E) education teachers often use textbooks. They discuss the use of textbooks in the PLNs. Teachers are encouraged to adapt activities in the textbooks and thereby explore new ways to make learning outcomes visible. They often use specific classroom observation instruments and tools to assess students' inquiry and design skills (Van Graft & Klein Tank, 2018). They also express the need for tools to help them analyze the quality of S&T activities and improve them. Figure 1 shows an example observation list for analyzing S&T-activities in early childhood education.

S&T(E) observation instrument
1. Is the activity embedded in a broader context?
2. Is student's curiosity and inquiry supported?
3. Is content from other domains, like geography or history, involved in the activity?
4. Are students developing S&T reasoning skills?
5. Are generic skills, like language or mathematics, involved?
6. Extra: do students use real materials?

Figure 1. Tool developed in a PLN for analyzing S&T activities in early childhood education

For example, a S&T textbook used in a school in the northern part of the Netherlands includes tests at the end of each theme to assess students' S&T content knowledge. However, this textbook does not provide tools for assessing students' S&T skills. Therefore a PLN consisting of teachers and researchers collaborated to develop a tool to assess learning outcomes. They based their tool on the learning trajectories of inquiry and design in primary education developed by the national institute for curriculum development in the Netherlands (SLO) (Van Graft & Klein Tank, 2018). Teachers in the PLN indicated that the tool should enable both teachers and students assess learning outcomes. They operationalized learning outcomes of using steps of inquiry- and design-based learning into more practical and recognizable goals for students. In the process teachers agreed that the tool should be a score sheet, which could be easily used by both teachers and students. This resulted in a score sheet based on the sheets developed Van Keulen et al. (n.d.) for research, but adapted for use in teaching. Categories in the sheet included: recognizing the problem, developing a solution, testing and improving the design, and presenting the design.

2.6 Reflection
Many teachers still experience challenges teaching S&T(E). However, teachers participating in PLNs and S&T(E) expert teacher groups did find a way to narrow this knowledge gap through joint practice-based research projects. A common theme in these PLNs is improving science education by better observing and assessing students' knowledge and skills before, during and after S&T activities. This resulted in several observation sheets and scoring methods being developed by teachers.

3. The challenge of connecting S&T(E) and M

3.1 Setting the scene
The four STEM perspectives are simultaneously needed to understand many current events. However, primary school teaching practice integrating the four disciplines is rare. In our experience as experts in the fields of mathematics and S&T(E) we notice that in most primary school curricula integrated STEM-activities have either a S&T(E) focus or a mathematics focus. In mathematics education, for example, there is a focus on mathematical procedures, and the scientific context provided is often irrelevant. By contrast, in S&T(E) teaching the embedded mathematics is usually just a tool providing (instrumental) procedures to work with numbers. In solving this problem of limited focus in integrating STEM domains, Lonning and DeFranco (2010) describe a continuum of 'independent mathematics – mathematics focus – balanced mathematics and science – science focus – independent science'. However, this continuum does not support simultaneous learning in all four domains. One reason that integration of these domains is problematic is that the domains are structured differently (Hotze & Keijzer, 2017). Key to mathematics are activities like symbolizing, modelling, formalizing, problem solving, pattern recognition, and generalizing. On the other hand, science focuses on explaining phenomenon in nature, using instruments and technology to do so. As a consequence, mathematics education sets the scene for mathematizing the world, while S&T education's focus is on research activities, designing, and explaining.
Several educational designers provide examples where integration of the STEM domains was successful in a sense that there was equal focus on two or more STEM-domains. These researchers, for example, showed that modelling with data, problem solving and data analysis were generative contexts to integrate science and mathematics in primary education (Mulligan & English, 2014; English, 2015). Problem solving, working with data, and modelling also appear in most frameworks for so-called 21st century skills (Voogt & Pareja Roblin, 2012). Moreover, dealing with data and modelling also typifies the mathematics needed for the future (Gravemeijer, Stephan, Julie, Lin, & Ohtani, 2017; Gal, 2024b). These focal points are also included in the draft of the Dutch national standards for mathematics in primary education (Prenger, et al., 2023).
The experiences of the PLNs however show that integrating the STEM domains in teaching places high demands on teachers' domain specific content knowledge and pedagogical content knowledge (Maass, Geiger, Ariza, & Goos, 2019).

3.2 Example: 'Growing grain for bread'
In a PLN in Amsterdam region, two teachers and two researchers developed an activity where science and mathematics are integrated for grade 4 (an age-group of approximately 10 years). The two teachers were specialists with a background in engineering and biology. While exploring possible activities in the PLN, teachers and educators in the PLN, first focused on mathematical thinking and mathematizing. They took the perspective of a specific domain and then changed this perspective – for example from mathematics to science – as a way to integrate both domains in the activity. While sharing and discussing this idea with the two teachers in the PLN, educators designed a learning environment for teachers, where they learned to change perspectives from one domain to the other, and an activity for primary school students where both domains were integrated.
The activity for the students focused on domain specific thinking and changing perspective from one domain to the other. After discussing this idea, one of the teachers in the PLN developed the activity 'The journey from grain to bread' (Bakker, Keijzer, & Hotze, 2023). Bread forms an important part of the daily diet for many children in the Netherlands. The development from grain to bread provides sufficient opportunities for students for exploring the situation, like from sowing to milling and baking bread. Moreover, this trajectory from grain to bread requires both mathematical thinking, like estimating the number of grains required for one loaf, and insights from biology, like how the grain grows.

When the teacher introduces the context of grain and bread, she starts by posing an open question: How do you get from grain to bread? In their responses students show what they know about sowing, harvesting and milling. After exploring the situation, the teacher introduces a more focused problem: 'Suppose we use the

school garden to grow wheat for bread, how many loaves of bread could we make?’ Students are invited to share their estimates: fifteen, three, less than one. The teacher replies: ‘And how can we figure this out?’
The children come up with different approaches to solving the problem, starting with how much grain a loaf of bread requires or starting with how much grain it is possible to grow in the school garden. As most students favor the latter option, the teacher presents a map of the school garden and together with the students explores the garden’s area. When this is settled students formulate additional subproblems to solve the original problem. In the process they change perspective from biology, namely how grain grows, to mathematics, the number of stalks per plant (Figure 2).

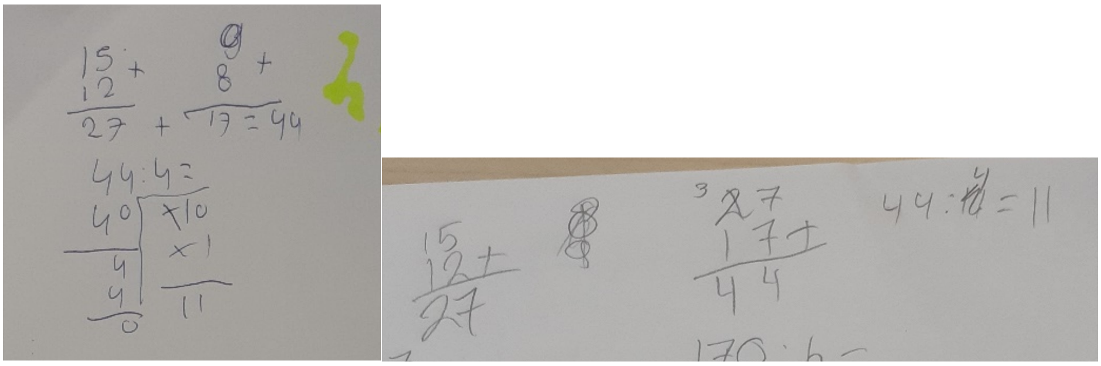

Figure 2: Student work of stalks per plant.

The students investigate the multiplicative structure of the problem and calculate, moving from the number of stalks per plant to the number of grains per stalk. They do this by counting and schematizing the result to help add the numbers. Multiplication emerges here as repeated addition.

Actual grain available during the activity allows students to investigate the grain as a substance, by feeling, tasting and grinding it. They also share their observations about the smell, the taste and strength of the grain. Eventually, the ground grain, in the form of flour, is weighed. When the students finally combine their mathematical findings, they conclude that a total of 338,800 grams of flour can be produced in the school garden. One loaf contains between 200 and 500 grams of flour, so the teacher suggests assuming 338.8 grams per loaf. Together they conclude that 1000 loafs of bread can be produced in the school garden. As this is obviously an unrealistically large number, the teacher adds: we probably miscalculated somewhere.

3.3 Reflection

The ‘grain and bread’ activity is an example of how mathematics and science can be integrated in teaching. The context provides opportunities to explore biological aspects of grain growing and stimulates mathematical modelling and schematizing. In doing so, students learn how grain is used to make bread. The context of growing grain in the school garden also helps them mathematize the situation as multiplication (or repeated addition).
The teacher – who also designed the activity – saw how the context allowed students to engage with two STEM domains: science (biology) and mathematics. In supporting students’ mathematizing process, she helped students find the multiplicative structure in the situation. She however translated this into calculating the answer, where in the end the number calculated proved to be wrong. In fact the focus on calculation moved students’ focus away from mathematizing and from wondering if the answer could be correct. These processes are both key to integrating mathematics with STEM and are somewhat neglected here. Focus on round numbers or using a calculator might keep the student focused on the mathematizing. Generally, our experiences here confirm the need for teachers’ domain specific content knowledge and corresponding pedagogical content knowledge. Moreover teachers need to be able to scaffold these domain specific requirements as well as changing perspective between domains during the activity.

4. The challenge of ‘Maker literacy’ and ‘Data literacy’

4.1 Introduction

The continuous development of new digital artifacts influences education, work and leisure. The rapid pace of development poses challenges for carefully rethinking education and preparing for this changing technological context. In this section we describe two areas where tools and technologies are used and associated skills are needed. New teaching standards in the Netherlands require that students and teachers develop new 'literacies' in these areas (Kampman, et al., 2024). Here, students and teachers need support from well-designed curricula and textbooks. We report here on two areas that were the focus of two different PLNs:

- Maker literacy, where the focus is working with the combination of hands, head and heart, using both simple technologies like hammer and nail and also high-tech tools like 3D-printing and working with programming languages like Scratch.
- Data literacy, which for examples deal with artificial intelligence, vigilant on fake news, and computational thinking,

4.2 Maker Literacy

In primary education playing with and manipulating concrete materials is rapidly replaced by mere cognitive tasks. When children grow older, handwork is less valued by textbook authors and teachers. Although manipulatives are important tools for learning, this mode of learning is increasingly neglected in primary education. The overemphasis on cognition does not provide a proper balance for children to develop all STEM skills. The 'Maker Movement' or 'Maker Culture' emphasizes the use of hands and creation: learning-through-doing. This approach is supported by a variety of tools (Martin, 2015; Libow Martinez & Stager, 2014; Pijls, Van Eijck, Kragten, & Bredeweg, 2022).

The PLN that acted on this issue worked with different classroom examples:

- How to build a scale model of a house, where you connect the manual work with the mathematical activity to get the right proportions.
- How to design a fantasy car where the requirements are: The car must be fast, four people must fit in the car, and the design must have an innovative look. This assignment was done with the age group 11-12.
- How to use a 3D printer with children of age 11-12. This task was piloted at one of the PLN schools. The teacher provided support to accommodate the use of this technology in her teaching. However, the PLN discussion made clear this was an exception. Going forward, for this PLN we plan to set up a collaboration between the primary school and a school for vocational education nearby.

4.2 Data Literacy

Digital technology and the internet have now made data collection and data sharing omnipresent, and data analysis and big data are common ingredients in the news, business, government and other social sectors. Being data literate and understanding digital technology surrounding us is thus increasingly important (ACME, 2023). Data literacy is an especially urgent issue when data and facts are routinely published with no checks or compliance with norms. Users of new technologies often find it difficult to understand how the technology has been used, according to which rules, and what data underpins it.
Against this backdrop, new national key learning objectives on digital/data literacy were recently developed in the Netherlands (Kampman, et al., 2024). In line with this development a PLN consisting of primary school teachers, teacher educators and others developed different classroom tasks and activities to support data literacy:

- Makey Makey is an easy-to-use programming environment (Note: See https://makeymakey.com/). In one of the activities students aged 8-10 use Makey Makey to design a prototype program code. Students are then encouraged to reflect on their work and critically analyze the 'computional' activity of making something "work".
- Using the Scratch programming environment for students between 10-15 years, led to a discussion in the PLN of the time needed for computational thinking activities, like coding and programming. Teachers also discussed various tools that they used. This discussion touched upon whether teaching and learning data literacy should be kept separate or included in other school disciplines like mathematics or language (Note: For background information see scratchjr.org and scratch.mit.edu.)

Two other topics for discussion were typical in the PLNs: namely 'critical thinking' and the use of artificial intelligence (AI). Critical thinking is needed for interpreting news and social media. Teachers in the PLN elaborated on ways to support students in participating productively in social media discussions. AI was discussed in one of the PLNs in relation to technology lessons, as a part of tools like Adobe Photoshop and Illustrator.

5. Strong pedagogy and content knowledge for teaching STEM

5.1 Introduction

Shulman defined Pedagogical Content Knowledge (PCK) almost forty years ago and his research (Shulman, 1986) still helps better understand of domain specific pedagogy. In PCK content knowledge and pedagogical knowledge coincide. PCK represents the blending of content and pedagogy into an understanding of how particular aspects of subject matter are organized, adapted, and represented for teaching. This is especially true for STEM education (STEM-PCK) where teachers need both strong pedagogical and content knowledge and skills to be effective. Researchers have reiterated this for both science and mathematics (Loughran, 2004; Grgurina, Barendsen, & Zwaneveld, 2014; Gresnigt, Taconis, Van Keulen, Gravemeijer, & Baartman, 2014).

5.2 Developing STEM-PCK

All the work from PLNs described in this chapter focused on the connection between pedagogy and content knowledge for the STEM disciplines. In our experience, working in PLNs resulted in the growth of teachers' skills and experience. However, teachers in the PLNs are not representative for all teachers. The PLN teachers were more interested in STEM subjects and their content knowledge exceeds that of many other teachers.
We saw that PLNs can play an innovative role within and across institutions. They help strengthening STEM activities in schools, building practical examples which can then be used by others, thus supporting the network of schools and teacher education institutes.
This relates to another learning related to supporting the development of teachers' content knowledge and STEM skills and attitudes: teacher education curricula should incorporate a firm foundation of STEM domains.
A final aspect of adequate attention to STEM-PCK is to have someone within the school responsible for supporting STEM. This idea is not new. The 'ICT-coordinator' and 'mathematics coordinator' were introduced more than 25 years ago in Dutch primary education. However, these professionals focus on one STEM domain only. It would be helpful to organize STEM-wide professional support in the schools.

6. Conclusions and discussion

In this section we summarize results from the Dutch Sprong STEM project (2021-2024). We have discussed examples of how PLNs in different regions facilitated primary education STEM development. We described STEM education in its societal context and specific issues like alignment, integration, assessment, teacher education and inquiry-based learning. We have showed how the PLNs catalyzed regional and nationwide STEM education development. Drawing on these experiences, we make three general recommendations for developing STEM in primary education.

6.1 Recommendation 1 - Design a connected STEM pedagogical content knowledge (PCK) foundation for all teachers involved

Developing teachers' content knowledge and their pedagogical content knowledge can help teachers realize high quality science (STE) and mathematics (M) activities in their teaching. This applies to individual STEM domains as well as STEM as an interconnected whole. We found that PLNs in which teachers, researchers and educators work cooperatively on themes adopted from a STEM perspective are a promising means to achieve this.

6.2 Recommendation 2 - Involve multiple institutions and backgrounds in PLNs

As PLNs may provide a way to enhance STEM education, carefully composing PLNs is crucial. A variety of professional backgrounds in a PLN is essential. We found that in order to support STEM education, the PLN should include teachers, educators, researchers, and curriculum developers. Moreover, successfully learning and developing in a PLN depends on a broader regional approach, where PLNs reflect cooperation between school boards and higher education institutions.

6.3 Recommendation 3 - Make 'STEM-connections' in national standards, and in curricula in primary education and teacher education

STEM education development grows out of local initiatives, where PLNs provide ready-made materials and ideas for practice. But more is needed. STEM education needs to be secured at the regional and national levels. Teacher education needs to explicitly embed STEM in the curriculum. Teacher education institutes can thus set an example for primary education. Moreover, both primary education and teacher education curricula are helped when the STEM domains and the interconnected nature of STEM are grounded in national standards.

7. Final remarks

We began this chapter by identifying four challenges in STEM-education in Dutch primary schools. We focused on assessment and showed that the nature of the STEM domains required revisiting general ideas on assessment. Exploring an activity in primary education, we elaborated on the M (for mathematics) in STEM. We found that integrating mathematics and science is hindered by a mere focus on mathematical procedures. These findings relate to the third challenge, namely teachers' PCK (pedagogical content knowledge). We saw that teachers' content knowledge is crucial for STEM in primary education, as it is essential for PCK development.

These challenges originated in recent developments in STEM education. PLNs consisting of teachers, educators and researchers, took broad and recognized issues in STEM education as the starting point to learn co-operatively. This cooperative learning subsequently formed the basis for the recommendations we make here. We take the position that developing STEM education in primary school requires a permanent dialogue between people in the field of primary education and researchers. In doing so we, researchers in the field, consider teachers as co-researchers, and aim to co-operatively develop STEM in Dutch primary education.

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