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Inclusive STEM Teaching from a Language Perspective: Teacher Learning in a Professional Development Program

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ABSTRACT

Worldwide, pupils with migrant backgrounds do not participate in school STEM subjects as successfully as their peers. Migrant pupils' subject-specific language proficiency lags behind, which hinders participation and learning. Primary teachers experience difficulty in teaching STEM as well as promoting required language development. This study investigates how a professional development program (PDP) focusing on inclusive STEM teaching can promote teacher learning of language-promoting strategies (promoting interaction, scaffolding language and using multilingual resources). Participants were five case study teachers in multilingual schools in the Netherlands (N = 2), Sweden (N = 1) and Norway (N = 2), who taught in primary classrooms with migrant pupils. The PDP focused on three STEM units (sound, maintenance, plant growth) and language-promoting strategies. To trace teachers' learning, three interviews were conducted with each of the five teachers (one after each unit). The teachers also filled in digital logs (one after each unit). The interviews showed positive changes in teachers' awareness, beliefs and attitudes towards language-supporting strategies. However, changes in practice and intentions for practice were reported to a lesser extent. This study shows that a PDP can be an effective starting point for teacher learning regarding inclusive STEM teaching. It also illuminates possible enablers (e.g., fostering language awareness) or hinderers (e.g., teachers' limited STEM knowledge) to be considered in future PDP design.

Keywords: inclusive STEM education, teacher learning, multilingualism, scaffolding language, professional development

INTRODUCTION

Worldwide, teachers face the challenge of providing high quality teaching to pupils with migrant and heterogeneous language backgrounds (henceforth: migrant pupils). Many of these pupils do not feel included in education and do not achieve in line with their academic potential (OECD, 2016, 2018). Although the school careers of migrant groups show upward mobility, the achievement gap is significant and persistent (Andon et al., 2014). This problem is particularly pressing for STEM education, as it causes serious loss of potential (Van den Hurk et al., 2018). Society nowadays demands professionals with backgrounds in STEM. Many pupils show interest in STEM, but their attitudes decline in the middle grades (Barmby et al., 2008) and relatively few teenagers opt for

STEM in higher education (Van Tuijl and Van der Molen, 2016). Amongst migrant pupils, STEM careers are less popular (OECD, 2008).

For migrant pupils' inclusion and achievement in STEM, language is one of the key factors. Language is fundamental to thinking and social interaction (Schleppegrell, 2004; Vygotsky, 1962). The latter comes to the fore in the discursive nature of STEM education, in which classroom interaction, the elaboration of ideas and the explanation of natural phenomena are central. Participation in STEM discourse strongly depends on proficiency in discipline-specific language (Gibbons, 2002) and teachers play a crucial role in migrant pupils' development of such language. Many teachers, however, experience difficulty in teaching STEM to migrant pupils (Banilower et al., 2013; Lee et al., 2007; Ünsal et al., 2016; Weinburgh et al., 2017). They tend to simplify or avoid language in STEM classrooms, as a result of which migrant pupils miss opportunities for (second) language development, widening the aforementioned gap (Lee, 2005) and reinforcing deficit views of migrant pupils (Van Laere et al., 2014). Consequently, migrant pupils are particularly disadvantaged in STEM education (Lee and Buxton, 2010).

The context for this study is a project where we aimed to promote primary teachers' inclusive STEM teaching from a language perspective through a professional development program (PDP). Rather than viewing (second) language development as a remedial endeavor taking place *outside* the mainstream classroom (as criticized by García, 1988), we centralized subject-specific language development *within* the mainstream content classroom (Bravo et al., 2014). Such content-based approaches have been argued to not only contribute to (all) pupils' language and content knowledge development simultaneously (Karlsson et al., 2019; Leckie and Wall, 2017; Rutt and Mumba, 2020), but to also reduce the achievement gap between native speakers and migrant pupils in the classroom (Gibbons, 2009). Research has yielded several strategies that have proven successful in promoting language development in the subjects. These include promoting classroom interaction around subject matter such as science (Osborne, 2007), language scaffolding (Gibbons, 2002; Smit et al., 2013), and the use of mother tongues for learning (also referred to as pedagogical translanguaging; García and Wei, 2013).

Despite the available knowledge regarding language-promoting strategies, teachers in several countries, such as the Netherlands and Nordic countries, have been found to struggle with the uptake of these strategies in their teaching practices (e.g., Onderwijsraad, 2017; Ragnarsdottir, 2015). The aim of this study is to investigate how a PDP focusing on inclusive STEM teaching from a language perspective can help overcome these difficulties, and what factors support or hinder teachers to use the strategies that are known to be effective.

THEORETICAL BACKGROUND

Fostering Inclusion in STEM Education: Meeting Discipline-Specific Literacy Demands

In this study, we adhere to the notion of inclusion as "an ongoing process aimed at offering quality education for all while respecting diversity and the different needs and abilities" of pupils (UNESCO IBE, 2008, p. 18). As noted by UNESCO (2008), many children in education drop out when their mother tongue is not the official language of schooling. This implies that another approach to language in the STEM classroom is needed to allow for all pupils' participation. Such an approach requires teachers' understanding of the discipline-specific language demands to foster migrant pupils' access to curricular content (DiCerbo, 2014).

STEM has been advocated as a powerful instructional context for language-promoting STEM education (Stoddart et al., 2002). It involves a teaching and learning process that is similar to practices of professional scientists, and thus includes inquiry-based elements (National Research Council, 2007). Through inquiry-based STEM, pupils engage in sequences of predicting-observing-explaining (White and Gunstone, 1992), usually by conducting hands-on investigations (Windschitl et al., 2008). As argued by Furtak and Penuel (2019), scientific inquiry should not encompass content-free investigations, but rather promote pupils' incremental sense making and explanations of natural phenomena. This inevitably requires proficiency in academic language (Lemke, 1990), that is, "the language used in school to learn, speak and write about academic subjects" (Valdez et al., 2005, p. 127). STEM concepts central to inquiry (e.g., 'sound', 'plant growth') should be introduced and used in connection to other related concepts and phrases, rather than in isolation. Language functions that are fundamental to STEM, such as hypothesizing, describing, justifying, and explaining, should also gain explicit attention (Bunch, 2013). This requires teacher proficiency concerning the establishment of productive classroom talk, as well as awareness of genres for schooling needed to make meaning in the subjects (Derewianka, 1990).

Language-promoting Strategies

To centralize discipline-specific literacy demands, several language-promoting teaching strategies have been put forward in previous research. Four of these strategies, with their roots in different disciplines (e.g., STEM education, second language acquisition theory), formed our operationalization of inclusive STEM teaching.

First, *promoting interaction about STEM content* (both verbal and written) is crucial for inquiry STEM learning (OECD, 2016). Teachers are to deliberately elicit pupils' active contributions to classroom interaction, for instance, by allowing wait time, or by posing open and thought-provoking questions (Osborne, 2007; Scott, 1998). All modalities used in subject-specific classroom interaction (listening, speaking, reading and writing) should be part of STEM teaching (Gibbons, 2002).

Second and third, *interactive* and *designed scaffolding* can foster inclusive STEM classrooms. Originally introduced by Wood et al. (1976), scaffolding typically refers to a kind of temporary, adaptive help, offered by a teacher to pupils, and directed at handover to pupils' independence (i.e., skills or competence; Van de Pol et al., 2010). In this study, scaffolding is directed towards academic language development. Two types of language scaffolding are distinguished (Gibbons, 2002). *Interactive scaffolding* is help offered adaptively in live interaction with pupils. Interactive scaffolding strategies include: reformulating pupil (spoken and written) utterances, asking for more precise (spoken and written) language, referring to features of the targeted language, asking how written text can be produced or improved, repeating correct (spoken and written) utterances, and making explicit the quality of pupil contributions (Smit et al., 2013; Van Driel et al., 2018). *Designed scaffolding* refers to planned language support for reading, talking and writing that is embedded in instructional materials or activities. Examples include writing frames that offer support in the writing (e.g., explanations, reports), model texts, and word lists including STEM concepts and formulations.

Fourth, *using multilingual resources* (i.e., home languages) that pupils bring to the classroom has been advocated (García and Wei, 2013). Previous research suggests that using home languages can improve children's participation in STEM education and can have socio-emotional (Infante and Licona, 2021) as well as cognitive benefits (Espinosa and Herrera, 2016). Using multilingual resources enables pupils to access the knowledge and skills they master in different languages. These resources can be human (e.g., other pupils or teachers who share the same home language), digital (e.g., translation tools, or multilingual websites) as well as paper based (e.g., books in multiple languages).

Promoting Teacher Learning for Inclusive STEM Education

To promote inclusive STEM education from a language perspective, teacher beliefs regarding linguistic diversity, the integration of language in content teaching, and the use of home languages are key (Garza and Arreguín-Anderson, 2018; Tan, 2011; Ticheloven et al., 2021). STEM teachers, however, often have low expectations of migrant pupils and regard pupils' home languages as an obstacle rather than a mediating tool for learning. Consequently, they are often resistant towards a focus on language (Lucas and Villegas, 2013). Such beliefs have proven difficult to alter (Lee et al., 2007), all the more because in most countries teacher education programs do not prepare teachers for teaching in linguistically diverse settings (Lyon, 2013; Rutt and Mumba, 2020). Complicating matters further, primary teachers often lack a knowledge of STEM, have limited pedagogical content knowledge, and demonstrate low self-efficacy with regard to teaching STEM (Traianou, 2006; Van Aalderen-Smeets et al., 2012). As such, the challenge of promoting inclusive STEM teaching is multifaceted.

To address challenges in professional development of teachers, Bakkenes, Vermunt, and Wubbels (2010) have put forward four learning activities: 1) learning by experimenting, such as trying out new instructional materials; 2) learning in interaction with others, such as teachers or researchers); 3) using external sources, for example viewing exemplary video materials; and 4) consciously reflecting on one's own teaching practices, for instance by filling in logs. Other key features of teacher professional development mentioned in the literature include a strong focus on subject content (Desimone, 2009; Van Veen et al., 2012), adaptivity to teachers' contexts and needs (Lyon, 2013; Putnam and Borko, 2000), as well as the opportunity for teachers to take ownership of their learning and enactment (Davis, 2002). Furthermore, a connection between what teachers learn to their classroom instruction has been advocated (Borko et al., 2010). Specifically in the context of inclusive STEM teaching, working with instructional materials that focus on subject-specific language use seems crucial. Research has shown, however, that even when working with such language-supportive materials, the enactment of language-based STEM teaching remains challenging for teachers (Lee et al., 2007; Smit et al., 2018).

Instructional Materials, Professional Development Program and Research Question

In this section, we first describe the design and nature of instructional materials that were provided to participating teachers so as to promote inclusive STEM teaching in their classrooms. Second, we describe the overarching professional development program (PDP) in which these instructional materials were central, leading to the research question.

A multidisciplinary, international project team designed three language-promoting STEM teaching units on sound, maintenance and plant growth. These topics were chosen to cover a wide range of (primary) curricular content (see **Table 1**). The project aimed to develop natural matches between different types of science and

Table 1. Central concepts and learning goals of the three teaching units taught by teachers of this study

Teaching unit	Unit 1: Sound	Unit 2: Maintenance	Unit 3: Plant growth
Central concepts	Sound, vibration, frequency, volume, decibel, pitch, bright/dark tones, resonance, echo, model, outer-middle-inner ear, ear canal, eardrum, hammer, anvil, stirrup, air, weight, density.	Maintenance, sustainability, production costs, function, safety, appearance, design, reparation, life expectancy	Plant, animal, photosynthesis, carbon dioxide, oxygen, gas, sugar, nutrients, energy, light, water, root, stem, leaves, embryo sprout, soil, seed coat
Content learning goals	Describe how sound is produced, how it travels and is perceived by the ear. Identify and describe characteristics of air and its composition.	Describe how a product can be designed in such a way that maintenance can be carried out. Describe reasons for maintenance related to function, sustainability and cost.	Identify and describe central characteristics of plants and seeds: embryo, food storage, seed coat, root, stem, leaves and flower and explain the function of these parts. Identify and describe factors that influence plant/seed life and growth, such as water, sunlight, carbon dioxide gas.
Inquiry-based learning goals	Perform simple systematic inquiries based on given plans (design, carry through and evaluation). Participate in the process of formulating questions and experimental follow up plans that can be systematically carried through. Document the inquiries with tables, images and in written reports. Search for information about science using different sources and reason about the usefulness of the information and sources.		

Report: Maintenance (lime removal)

Introduction
This experiment shows that…

Method (*you can use words and drawings. Use verbs in the past tense to show what happened*)
The experiment was conducted in the following way:
We…

Observations
- Before the vinegar was added, we saw that…
- After the vinegar was added, we saw that…

Conclusions
Lime can be removed by liquids such as…
We call that process…
That is useful for materials such as … and …, because …

Figure 1. Example of a writing frame used as a designed scaffolding tool in the maintenance unit of the PDP

technology pedagogies and the four strategies for language development, with a focus on inquiry-based learning but not limited to this pedagogy. For instance, the 'sound module' was more oriented toward a conceptual change approach, whereas the module 'plant growth' was based on a mix between inquiry-based learning (seed germination) and conceptual change (photosynthesis). Inquiry-based learning is a term for an approach that is more commonly associated to science pedagogy rather than technology. However, in this project, the 'maintenance' unit also incorporated inquiry elements. For example, the worksheet 'inquiry around a product' provided scaffolds for the students to strengthen their investigation of 'form, function and possible optimization'. The worksheet not only promoted investigation, but also the gathering and analyzing information (typical of scientific exploration).

Following a design-based research approach (Bakker, 2018), the design process allowed for empirical findings to influence subsequent material development and, consequently, teaching practice. The aforementioned four strategies for inclusive STEM teaching (promoting interaction, interactive and designed scaffolding, and using multilingual resources) were embedded in the instructional materials. For instance, the description of lessons included the use of designed scaffolding (e.g., model texts or writing frames; see **Figure 1**) or suggestions for the use of home languages during teaching (e.g., small group discussion in shared home languages, see Gómez Fernández, 2019). Explicit attention was also paid to targeted language in instructional activities.

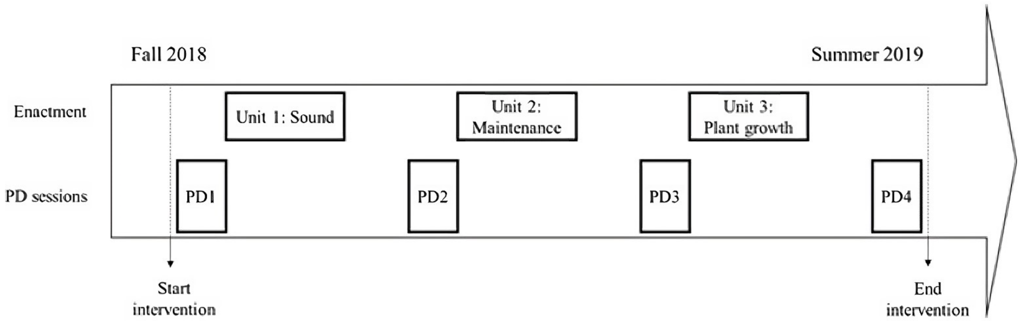

Figure 2. Timeline of the PDP on inclusive STEM teaching from a language perspective

The PDP was developed by researchers from the three participating countries and included four sessions that were similar in terms of objectives, key topics, and PD activities across countries. The sessions lasted between two and a half and four hours, and took place between fall 2018 and summer 2019 in all three countries (see **Figure 2** for a timeline of the PDP). Program participants were 23 primary teachers. Twelve teachers were from the Netherlands, six from Norway and five from Sweden (21 women, two men, M_{age} = 39.7 years, age range: 23–64 years). The total number of hours participants spent on the program, including preparation and enactment of STEM lessons, was about 50 h. They had an average of 13.6 years of experience (range: 1–40 years). Three of them grew up with a mother tongue other than the national language (Turkish, Berber Moroccan and Albanian). Participants taught in 4th to 8th grade classrooms with a percentage of migrant pupils that ranged from 15 to 100%. From this group of participants, five teachers constituted the case studies reported in this study.

The sessions were led by researchers-educators from the local teams. The first three sessions were developed so as to help teachers become acquainted with the three STEM topics and the instructional materials, to promote their awareness of language use in STEM, as well as to gradually foster their independence regarding the uptake of language-promoting strategies (cf. Smit et al., 2018). To realize the latter, each language-promoting strategy came across several times in the PD activities; at first by introducing them and verifying teachers' familiarity with them; later on, by asking teachers to reflect on their own or others' use of the strategies (for instance by watching and discussing classroom video fragments, or by reading and discussing excerpts of classroom interaction).

To promote teacher learning during the PDP, the aforementioned four learning activities (Bakkenes et al., 2010) were included in its design. To promote teacher reflection, for example, teachers were asked to verbally reflect on their teaching practices, on the quality and their use of the instructional materials, and on pupils' participation and progress in response to the inclusive STEM lessons. Reflection was also promoted by filling in reflective logs after enacting each of the teaching units. Learning by experimenting was combined with a focus on STEM content, so as to empower participating teachers regarding their knowledge and self-efficacy in STEM. During sessions, participating teachers were themselves exposed to scientific inquiry (i.e. did science experiments), in order to experience and more deeply understand the scientific phenomena at stake (cf. Minner et al., 2010). Furthermore, teachers were encouraged to adapt instructional activities for use in their own contexts.

When teachers are to implement innovative approaches that have proven to be effective (e.g., the enactment of language-promoting strategies for content learning) they have to understand how they work and how they can be enacted adaptively within their own contexts. *Evaluating teacher learning* is a crucial step as it can show how the professional development program (including instructional materials) has the potential – as a proof of principle – to help teachers realize the innovative approach, in this case inclusive STEM teaching (cf. Bakker, 2018). For investigating what teachers learnt during the PDP, we adhere to Bakkenes et al.'s (2010) conceptualization of teacher learning as "an active process in which teachers engage in activities that lead to a change in knowledge and beliefs (cognition) and/or teaching practices (behavior)" (p. 536). To evaluate teachers' uptake of language-promoting strategies in their own contexts, and as such provide a proof of principle regarding the potential of the designed PDP for inclusive STEM teaching, we ask: *what did teachers learn during a PDP focusing on realizing inclusive STEM education?*

METHODS

Setting: Three National Contexts

The three participating countries that worked as contexts for this study share the fact that they have one official language spoken by the majority of the population (Dutch, Swedish and Norwegian; the two other official languages are Frisian in the Netherlands and Sámi in Norway). These majority languages play an essential role in

Table 2. Teaching and classroom information for the five case study teachers participating in this study

Teacher	Country	Years of teaching experience	Classroom year/group	Approx. percentage of children with multilingual background in the classroom/s (%)	Home languages present in the classroom/s
Tina	the Netherlands	40	7/8	30	Arabic, Egyptian, English, Finnish, German, Moroccan, Serbian, Turkish
Sarah	the Netherlands	9	6	100	Moroccan, Somali Turkish
Charissa	Norway	15	7	8	Arabic, Polish, Somali
Katy	Norway	22	6	13	Arabic, English, Serbian, Somali
Melany	Sweden	2	4	15	Arabic, Danish

citizenship and education. The three countries are also inhabited by speakers of minority languages which arise from regional variations of the official languages or from migrant communities. This landscape makes these countries different to others, like Canada or Switzerland, where more than one majority languages are spoken. The three countries thus face similar challenges as to inclusion of migrant pupils in STEM classrooms (e.g., achievement gaps in STEM, language support difficult to realize in the classroom). There are, however, remarkable differences in approaches across the three national contexts in terms of policies and support for teaching in multilingual classrooms (Hajer et al., 2018; NAFO, 2020; Onderwijsraad, 2017). In general, Sweden puts language scaffolding at the core of national professional development programs, while Dutch and Norwegian governments offer only general guidelines to teachers. Sweden has more availability of staff such as special educational needs experts, second language teachers, and mother tongue support teachers than Norway and the Netherlands. In Sweden, newly arrived pupils go to mainstream education as soon as possible, while in the Netherlands and Norway they are separated from native peers for a period of time. Finally, although mother tongue instruction is common and encouraged in Sweden, this is not as much the case in Norway and hardly in the Netherlands.

Participants

Participants in this study were five case study teachers out of the 23 that participated in the inclusive STEM program. The case study teachers were all women (M_{age} = 44.4 years, age range: 28–64 years).Two are from the Netherlands, among whom one has Berber Moroccan as mother tongue, two from Norway and one from Sweden. **Table 2** shows information related to the teaching experience and classrooms of the case study teachers.

The case study teachers were selected both based on their willingness to fill in logs and participate in interviews, and the variety of national contexts, years of teaching experience, and percentages of migrant pupils in the classroom (see **Table 2**). When the project started it was not common practice to consult ethics committees for ethics approval. However, we did take steps to be transparent. Verbal informed consent was obtained from participants in the study, after explaining the project's focus to interested teachers (verbally as well as in writing). All participants entered the project voluntarily and had the right to withdraw from the study without giving any explanation and at any time. In **Table 2** and this article, names of the teachers have been modified, and other identifying information from participants has been left out, in an effort to protect participants' privacy to our best knowledge.

Instruments and Data Collection

The main source of data for this study are individual interviews with the five case study teachers, conducted after each teaching unit of the PDP (three interviews per teacher in total). An interview format was developed. The format was based on specific teachers' answers as written in the digital logs after completion of the teaching unit, as well as follow-up questions formulated by a researcher from the national team aimed at further elaboration on the teacher's digital log answers (e.g., *Can you give examples of how you tried to include all pupils in classroom interaction?*). Particular attention was given to log answers that included a clear change in knowledge, beliefs, or practice regarding inclusive STEM teaching, or in which a particular challenge was expressed (e.g., regarding the use of home languages). The interviews were conducted by researchers from the three national teams. They were audio recorded and transcribed verbatim.

A supplementary source of data are the digital logs themselves, filled in by the teachers after each teaching unit of the PDP before the interview (three logs per teacher in total, except for the teachers from Norway, which only filled in the first two logs). The digital logs were devised using a reflective log format with 13 questions, informed by the aforementioned four learning activities by Bakkenes et al. (2010) and focused on teachers' use of the instructional materials, their pupils' participation during the unit, and the enactment of the language-promoting strategies (e.g., *Which language-promoting strategies did you enact while teaching the STEM lessons?).*

Table 3. Categories of teachers' self-reported changes along with description and examples (cf. Bakkenes et al., 2010)

Category (code)	Description	Example
Changes in Knowledge/ Beliefs (CKB)	The teacher explicitly reports a change in (or confirmation of) what he/she knows or believes regarding his/her teaching in relation to the PD program.	"I only now realize that language may be central to learning."
Intentions for Practice (IP)	The teacher explicitly reports an intention to change (or hold on to) teaching practice(s) as a result of the PD program.	"I want the children to write more, so far they have only spoke out loud about the experiments."
Changes in Practice (CP)	The teacher explicitly reports a change in his/her teaching practice as a result of the PD program.	"I see myself, right now, as being more careful when formulating questions in all my courses and with all my pupils."

Data Analysis

To answer the research question, we investigated case study teachers' learning processes during the program based on the interview data. The analysis was conducted by the first, second and sixth authors.

To conduct the analysis, we drew on the framework developed by Bakkenes et al. (2010) for studying teacher learning in the context of educational innovation. It distinguishes four main categories of self-reported teacher learning: Changes in Knowledge and Beliefs, Intentions for Practice, Changes in Practice, and Emotions. The first and second authors used the framework to build a codebook containing a description of each category and examples of words and statements that could be indicative of each category (cf. Smit and Van Eerde, 2011). Because teachers hardly *explicitly* reported on emotions during the interviews and because these statements were hard to code reliably, we decided to leave the category of emotions out (cf. Smit et al., 2018). The three remaining categories used in this study are summarized and illustrated in **Table 3**.

The second author selected and coded teacher utterances that expressed self-reported learning in an explicit way. Subsequently, the sixth author coded a subset of 16 utterances independently (sec. the $2n^2$ rule, see Cicchetti, 1976). The coding of both authors was compared in terms of interrater reliability: substantial agreement was obtained (κ = .70).

Based on the coding, we wrote up a descriptive summary for each case study teacher regarding their learning outcomes in relation to the four language-promoting strategies. Subsequently, all summaries were compared (cross-case analysis; Borman et al., 2012) resulting in an integrative narrative per strategy including 1) a summary of the *distribution of reported learning outcomes* (among the categories of Changes in Knowledge and Beliefs, Intentions for Practice and Changes in Practice), and 2) an overview of remarkable *common learning outcomes* and *individual learning outcomes*.

Last, researchers from the three national teams validated the narratives based on their reading. No contradictions were found between national researchers' experiences and our findings. For reasons of space, we only include the integrative narratives per strategy in the results section.

The digital logs were used as a means of triangulation, specifically, for the corroboration of the descriptive summaries. The second author read the digital logs filled in by the teachers, and, as with the interview data, selected and coded teacher utterances that expressed self-reported learning in an explicit way. The coded utterances from the digital logs (n = 13, in total for the five teachers) were then compared against the descriptive summaries of each teacher. We found no contradictions between interviews and logs and the self-reported changes found in the logs were related to those found in the interviews. However, the interviews contained additional reported changes to those of the logs, probably because interviews gave teachers more space for elaboration.

RESULTS

Promoting Interaction around STEM

Concerning the strategy of promoting interaction around STEM, all five teachers reported learning in the category of Changes in Knowledge and Beliefs (see **Table 4** for frequencies of this category in the interviews). Three teachers, Sarah (NL), Charissa (NO) and Melany (SE), also reported having incorporated this strategy more permanently in their teaching practice (Changes in Practice). The two Dutch teachers, Tina and Sarah, spoke about having intentions of incorporating this strategy into their future practice (Intentions for Practice).

Comparing teachers' reported learning accounts brought several commonalities to light. They all deemed promoting interaction around STEM a crucial strategy for the realization of inclusive inquiry-based STEM teaching. The most salient commonality concerned the value four out of five teachers attributed to *small group work*.

Table 4. Frequencies of reported learning outcomes (per category) for each teacher, in the strategy of promoting interaction around STEM

	Tina (NL)	Sarah (NL)	Katy (NO)	Charissa (NO)	Melany (SE)
Changes in knowledge and beliefs	7	3	2	5	1
Intentions for practice	4	3	-	-	-
Changes in practice	-	1	-	4	1

Charissa appreciated the "constant reminder of the importance of collaboration" in the instructional materials. Tina repeatedly shared the gained insight that more pupils participated in whole-class interaction if it was preceded by interaction in small groups. Katy (NO) realized to be better able to guide pupils' learning when they worked in small groups. Sarah reported in the first interview to have more actively promoted pupil collaboration and interaction in her STEM lessons – a remarkable change in practice, considering the more traditional, teacher-led whole-class culture in which she started the PDP.

A few other commonalities in reported learning were found, all occurring in two or three of the five teachers. The importance of *posing the right questions* was mentioned several times, albeit in different ways. While Tina became aware of posing open questions for provoking thinking, Sarah reported the belief that questions in STEM should make pupils curious. Charissa related this topic to her own knowledge of STEM, by stating that being well prepared allowed her to pose "better follow-up questions when spontaneous situations [arose in classroom discussion]". Also Tina came to understand the importance of "know-how" (in STEM) and "more background knowledge", and expressed the intention to read more about a STEM topic before its introduction in the classroom.

Both Tina and Melany expressed the belief for a *safe classroom climate* to be a prerequisite for promoting interaction around STEM. Inclusive STEM, in the following account by Melany, involves social norms such as helpfulness and honesty:

> you ask them to help each other and not make it into a weird thing by trying to cover it up, trying to have a pretty open climate. (…) we have to make sure that we help each other and they are pretty aware of who needs more help.

Another commonality across teachers concerned a focus on *more active STEM lessons*. Sarah expressed the intention to use less reading material and include more active (i.e. inquiry-based) assignments in her future STEM lessons. Melany, in the same vein, stated to have changed her teaching practice towards less reading of texts and more inquiry. Last, two teachers reported learning with regard to *writing in STEM*: Tina expressed the intention to incorporate writing so as to promote interaction, while Charissa reported to have included writing as part of her lessons.

Notable individual learning mainly concerned instances of raised awareness, for example regarding the importance of wait time for inclusion, which Charissa articulated as follows: "If I want the pupil to reflect, then I am very conscious that they should have ten seconds to think by themselves first." Other instances of awareness concerned the difficulty of realizing *all* pupils' participation in classroom interaction (Sarah), and the experience that promoting interaction helped pupils "who are otherwise more passive" to become more eager in STEM learning (Katy).

Scaffolding

In the case of *interactive scaffolding*, all teachers reported learning as Changes in Knowledge and Beliefs (**Table 5**). While only Sarah (NL) and Melany (SE) gave examples of Changes in Practice, the two Dutch teachers and Charissa (NO) reported having an intention to enact this type of scaffolding more in the future (Intentions for Practice). In four out of five teachers, reported learning of *designed scaffolding* was distributed over the categories of Changes in Practice and Intentions for Practice, with the only exception being Charissa, who reported a change in knowledge and beliefs once (**Table 6**).

Interactive Scaffolding

Table 5. Frequencies of reported learning outcomes (per category) for each teacher, in the strategy of interactive scaffolding

	Tina (NL)	Sarah (NL)	Katy (NO)	Charissa (NO)	Melany (SE)
Changes in knowledge and beliefs	9	2	3	1	2
Intentions for practice	1	1	-	1	-
Changes in practice	-	1	-	-	2

The comparison of case study teachers' reported learning with respect to interactive scaffolding demonstrated several commonalities. These included all teachers' *increased awareness* of the role of language in STEM and the importance to support (or scaffold) language development. In the third and final interview, for example, Katy (NO) stated that she had "become much more aware of learning language. (…) scientific concepts, expressions, everyday words, and the link between them. And that one has to be conscious of that all the time." Tina (NL) noted that her increased awareness of the importance to scaffold language led to a high degree of effort on her part, as she had become "busier" with the language aspect of her practice, in addition to content knowledge.

Interactive scaffolding strategies reported by four out of five teachers included *asking pupils for reformulation and/or asking for elaboration of their utterances*, in four teachers present in the forms of Changes in Knowledge and Beliefsand, in addition, Changes in Practice or Intentions for Practice. Sarah exemplified her enactment of this strategy as follows: "Today somebody said 'that thing'. And then I'll try to steer them: 'which thing are you talking about exactly?' So I focus very much on their language. How do you put something into words?" Sarah explicitly reported on asking pupils both for reformulation and elaboration. However, in the second interview, she remarked not having been able to ask for elaboration as much as in the previous unit on sound. This may be related to her lack of familiarity, also experienced by the other teachers, with the STEM content of the second unit (maintenance). This may have hindered teachers' realization of this interactive scaffolding strategy.

Another commonality concerned the *importance of introducing pupils to and reminding them of targeted STEM language*, explicitly expressed by three of the case study teachers (Tina, Sarah and Katy). Sarah explicitly reported a change in practice already after unit 1: "what I do differently than before, for example, is that I try really hard to use the right words. (…) I try to use not only everyday words, but also the content-related vocabulary." The same three teachers also expressed the importance of their own adequate language use (or "the need of facilitating terminology", cf. Katy) in STEM lessons. Notable is the focus on words (or concepts) when it comes to how these three teachers seem to envision language in STEM learning. As Katy put it: "And we worked on words and concepts all the time." Rather than focusing on ways of talking in STEM, or on language functions such as hypothesizing or explaining, the case study teachers tended to centralize STEM vocabulary.

Three teachers (Tina, Charissa and Melany) brought the act of *diagnosing* to the fore, albeit in different ways. While Tina reported on pupils' mastering of STEM words after frequently repeating them, Charissa expressed the challenge of diagnosing conceptual development both orally and in writing. Only Melany related STEM content knowledge to language, as she reported on diagnosing pupil understanding through their use of everyday or STEM language.

Other topics of learning were found for only some teachers. Two Dutch teachers expressed having incorporated the scaffolding strategies also in other subjects than STEM. Only Katy and Melany stated to *differentiate* in their enactment of scaffolding strategies, that is, to respond to levels of language proficiency in pupils, as centralized several times during the PDP. Finally, Melany was the only case study teacher who claimed, in the enactment of unit 2, to "say the same thing but in another way" (also called 'message abundancy' in scaffolding literature, cf. Gibbons, 2002). After unit 3 she stated to be already familiar with interactive scaffolding. These statements may be explained by Melany's Swedish context in which teachers are induced into scaffolding theory and practice from teacher education onwards.

Designed Scaffolding

Table 6. Frequencies of reported learning outcomes (per category) for each teacher, in the strategy of designed scaffolding

	Tina (NL)	Sarah (NL)	Katy (NO)	Charissa (NO)	Melany (SE)
Changes in knowledge and beliefs	-	-	-	1	-
Intentions for practice	2	1	4	-	-
Changes in practice	2	1	1	-	1

Common learning for designed scaffolding involved having incorporated tools to *support pupils' writing*. Four out of five teachers reported on having used tools such as a writing frame (in this study: a template for a report with sentence starters) and "Meet in the Middle" (a placemat in which pupils could collaboratively write hypotheses and predictions; Jakobsson and Kouns, 2021). Tina (NL) and Melany (SE) also discussed having incorporated the use of *visual materials*, such as drawing or printing pictures and linking them to new words. Designed scaffolding was also realized by writing up key words on the board or on word lists hanging on the wall.

The PDP, including the inclusive instructional materials, may have helped teachers to enact this strategy and to evaluate its usefulness for their practice. This can be seen in Tina's reflection after unit 3, "it is because of the previous units that I realized that writing on the [black]board is really good".

A final commonality concerns the fact that three out of five teachers expressed their intentions of using this strategy during units 1 to 3, and two of them also in the future (and in other subjects). However, teachers gave different individual arguments to explain the perceived usefulness of this strategy. Sarah (NL) explained that using a template allowed her to ensure that *all* pupils were involved in the writing tasks and in reflection upon science experiments. Tina remarked on the writing tools being useful to support pupils' predictions in science experiments. Katy explained in unit 1 that designed scaffolding tools were especially helpful for pupils to learn new vocabulary:

> I felt that they learned quite a few new words, but that I should try to get all the words in next time (…) we have to make some space for the words, so they are hanging there and they can see them all the time.

In sum, teachers' reported learning regarding interactive scaffolding concerned mainly Changes in Knowledge and Beliefs, while for designed scaffolding they concerned mainly Intentions for Practice and Changes in Practice. Despite this difference, which suggests that designed scaffolding – being embedded in teaching materials – may have been easier to incorporate in practice, both types of scaffolding strategies were deemed useful for inclusive STEM education, judged by teachers' increased awareness and altered beliefs, as well as their intentions to use scaffolding strategies in the future and in other subjects.

Using Multilingual Resources

Table 7. Frequencies of reported learning outcomes (per category) for each teacher, in the strategy of using multilingual resources

	Tina (NL)	Sarah (NL)	Katy (NO)	Charissa (NO)	Melany (SE)
Changes in knowledge and beliefs	-	3	-	7	-
Intentions for practice	-	3	-	-	-
Changes in practice	-	-	-	-	-

For the strategy of using multilingual resources, only two out of five teachers (Sarah, NL, and Charissa, NO) reported learning in the category of Changes in Knowledge and Beliefs (**Table 7**). Sarah was the only teacher to report learning in the category of Intentions for Practice. We found no explicit reports of Changes in Practice for this strategy in any of the teachers, showing that none of them explicitly reported having incorporated the strategy more permanently in their teaching practice.

Common reported learning for the strategy of using multilingual resources concerns three topics. First, both teachers (Sarah and Charissa) reported on Changes in Knowledge and Beliefs related to the use of *digital tools* to employ home languages in STEM. Charissa, for instance, stated that she realized that the use of digital tools "depends on how strong the student is. [The student] needs to be resourceful and independent". Second, both teachers mentioned *external staff* (such as parents, language teachers) to be important for the realization of this strategy. Third, both teachers reported on raised awareness concerning the challenge of *guiding pupils' conceptual understanding* when they are not proficient in home languages used. Sarah, for instance, expressed "you can't make sure they've formulated it correctly, or check to see if they've understood. (…) I don't think [how to best use this strategy] is clear to all of us [teachers]." We found one individual reported learning outcome for this strategy: It included Sarah's reflection on the need for *being prepared* for lessons to be able to use home languages, as well as the fact that it "requires a bit of daring".

DISCUSSION

The present study examined teachers' learning of inclusive STEM teaching from a language perspective against the background of a PDP. In response to our research question, two overall conclusions can be drawn. First, teachers increasingly recognized the importance of language-promoting strategies for inclusive STEM teaching, as apparent from changes in awareness, beliefs and attitudes over the course of the PDP. Second, Changes in Practice and Intentions for Practice were found to a lesser extent, implying teachers' struggles in the actual enactment of language-promoting strategies (in particular interactive scaffolding and using multilingual resources).

One obvious limitation of our study concerns the small number of teachers participating in this study. Further to this, our PDP only spanned four sessions, which leaves the question open whether a PDP of longer duration would have allowed teachers to not only increase their awareness but to also incorporate inclusive strategies more permanently in their STEM teaching practices (cf. Smit et al., 2018). Another limitation concerns the fact that this study did not include evidence of teacher learning beyond that presented through self-report (e.g., through classroom observations).

We now turn to factors brought to the fore by the case study teachers as key to their realization of inclusive STEM teaching, so as to tentatively inform the design of future PDP's.

Implications for Future PDP Design on Inclusive STEM Teaching

Teachers were asked to internalize a repertoire of language-promoting strategies in a relatively short amount of time, and to enact them responsively in their STEM lessons – a challenging task. The varying degrees of success with each strategy's enactment suggests, in general terms, that more attention should be given to teachers' previous experiences with the strategies (e.g., perhaps through a pre-entry questionnaire) and this information could then be incorporated in PDP design.

To realize the *promotion of interaction around STEM*, two factors seemed of relevance. First, teachers stated that a safe classroom climate is a prerequisite for inclusive STEM teaching (in line with Mercer's ground rules for talk, 2000, and with Yackel and Cobb's social norms, 1996). This implies that a PDP should include the topic of classroom interaction norms, so as to prepare teachers and pupils for inclusive teaching. Second, teachers realized that STEM content knowledge is a key factor for promoting productive interaction around STEM. This resonates with previous research highlighting the need for teachers to have an adequate level of subject matter knowledge in order to convey this knowledge to pupils (e.g., through explanatory representations, Hashweh, 1987). This aspect turned out to be underrepresented in the PDP reported here, as several teachers experienced their limited content knowledge as a shortcoming (particularly mentioned after Unit 2, on maintenance).

Concerning the strategy of *interactive scaffolding,* teachers particularly reported on increased awareness, both related to the central role of language in the subjects of STEM, as well as to their own modeling role for developing language proficiency in pupils. This finding reinforces awareness as an important step towards teachers' enactment of language scaffolding (cf. Smit and Van Eerde, 2011). To foster awareness, we promoted reflection on classroom practices in the PDP, for instance by watching and discussing video recording. A closer look at teachers' interactive scaffolding accounts brought an emphasis on STEM words rather than on language functions (e.g., predicting, observing or explaining) to the fore. A genre-based approach to subject teaching (Martin, 2009), in which teachers explicitly pay attention to a (text) genre's specific purpose (e.g., to *explain* a phenomenon), the particular overall structure (text organization in terms of stages or moves) and specific linguistic features (e.g., words and formulations; tenses and verbs used), could help students understand how language enables them to fulfil communicative goals in school and society and, more specifically, how they can use language themselves to make meaning in STEM (e.g., to *describe* an experiment). To promote genre-based rather than vocabulary-focused STEM teaching, we advocate the inclusion of a functional (genre-based) approach to language in future PDP design. Another recommendation is the incorporation of content knowledge development in PDP's designed for inclusive STEM teaching, because teachers' limited content knowledge may have hindered a functional approach to language in STEM, for it is primarily in language functions that the close relation between subject matter knowledge and academic language proficiency is established. *Designed scaffolding* proved an accessible strategy as it was embedded in the teaching materials. Providing teachers with such language-oriented instructional materials is therefore recommended as well for future PDP design focusing on inclusion. Capitalizing on students' writing in STEM, too, is another recommendation, based on teachers' accounts.

Explicit learning outcomes concerning *the use of multilingual resources*, last, were scarce. As in other studies, teachers expressed general positive attitudes toward the use of home language in the classroom (cf. Alisaari et al., 2019; Rutt and Mumba, 2020), but learning to enact this strategy appeared challenging. Individual accounts pointed to feelings of uncertainty surrounding the use of digital translators and the guidance of pupils using home languages unfamiliar to the teacher. As an enabling first step towards enacting this language-promoting strategy, teachers mentioned interaction with peers, parents or teachers who share pupils' home language(s). Concerning the results on the use of multilingual resources it is important to note that a richer picture could be obtained when adopting a broader analytical lens than explicitly reported learning only. Based on the study reported here we recommend to include conditions as to how home languages can be used by teachers who do not master these in PDP design, as well as to how external multilingual resources such as digital tools or parents can be used.

CONCLUSIONS

The findings of this study provide a proof of principle regarding the potential of professional development as an effective starting point for teachers' learning and enactment of inclusive STEM teaching from a language perspective. Features of future PDP can be adjusted to promote more (permanent) changes in practice in teachers, and to increase the employment of more challenging or unfamiliar strategies, such as using multilingual resources.

This study supports the idea that teacher professional development is key in the promotion of reform-oriented practices (Hart and Lee, 2003), in this case, the realization of inclusive STEM teaching from a language perspective.

In particular, the connection between STEM content knowledge and a focus on language development (cf., Leckie and Wall, 2017) was crucial, as reported by participating teachers. This study also supports our operationalization of inclusive STEM teaching from a language perspective. Teachers accepted and valued the set of language-promoting strategies as a repertoire that could be enacted in an integrated way, despite the challenges they experienced. Future research should further inquire, at the theoretical level, how language pedagogies relate to subject-specific demands, and at the practical level, how professional development and strategies can be refined to accommodate teachers' previous experiences and unique learning pathways.

LIST OF ABBREVIATIONS

NL – the Netherlands
NO – Norway
PDP – professional development program
SE – Sweden

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COMPETING INTERESTS

The authors declare that they have no competing interests.

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