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Effective characteristics of professional development programs for science and technology education

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ABSTRACT

Science and technology education has become increasingly important. However, for most teachers, it is challenging to provide this content. Therefore, professional development programmes are used to support teachers in this regard. In this qualitative study, effective characteristics that should be present in such programmes were identified. Moreover, four particular professional development programmes were investigated to see whether they included these characteristics. Eleven review studies and meta-analyses were analysed to identify the effective characteristics of professional development programmes for science and technology education. Five content characteristics were distinguished: focus, activities, collaboration, coherence of content, and duration. In addition, three contextual characteristics were distinguished: coherence with context, individual factors, and organisational factors. The materials from four professional development programmes for science and technology education were collected and analysed and interviews were held with principal investigators who were involved in the design of these programmes and with educators who worked with these programmes. The characteristics duration and coherence with context appeared to be fully addressed in respectively two and one programmes. The other characteristics were incorporated to a limited extent or not at all. Overall, the present study illustrated the apparent challenges in designing professional development programmes.

Science and technology education has become increasingly important (NETP 2010, National Research Council 2011). One reason for this is that the resulting knowledge and skills prepare students for participation in our constantly changing future society (Rennie *et al.* 2012). Moreover, science education is seen as a crucial aspect of our contemporary culture, and of that culture, all students should have at least some rudimentary understanding (Osborne and Dillon 2008). Finally, not enough students pursue a career in science to keep the knowledge economy running (European Commission 2004), and paying additional attention to science and technology education is expected to motivate students' choice of a science-related career.

In spite of the importance of science and technology education, a TIMSS study showed that only 27% of primary school teachers believe they are able to provide this type of subject matter (Martin *et al.* 2008). In addition, teachers usually display little attraction to this type of subject matter (Van Aalderen-Smeets *et al.* 2012). Therefore, teachers' professional development is seen as a crucial step in

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order to implement and sustain science and technology education (e.g., Hubers, accepted for publication, Van Driel *et al.* 2012, Sandholtz *et al.* 2019).

Despite the numerous programmes that have been developed to aid teachers' professional development regarding science and technology education (e.g., Akerson *et al.* 2009, Berry *et al.* 2009, Van der Valk and De Jong 2009, Banerjee 2010), it is often unclear whether they result in sustainable changes in the educational practice (Van Driel *et al.* 2012). However, studies investigating the sustainability of such professional development initiatives have shown thin or even disappointing results. This is not only the case for professional development for science and technology education, but for all types of professional development (Van Veen *et al.* 2010), including data use (Hubers *et al.* 2017) and lesson study (Wolthuis *et al.* 2020).

After engaging in professional development initiatives, teachers often make only superficial changes in their teaching behaviours or revert to their 'old' ways entirely after funding and support for their professional development are withdrawn (e.g., Coburn 2004, Hubers *et al.* 2017, McLaughlin and Mitra 2001, Spillane 2000, Wolthuis *et al.* 2020). Even when teachers try to continue innovating their teaching behaviour, there is a heightened risk of misuse and 'lethal mutations', thereby endangering the quality of the education they provide (McLaughlin and Mitra 2001, Hubers *et al.* 2017).

However, as teachers' professional development remains to be seen as one of the most important driving factors for improved science and technology education (Osborne and Dillon 2008, Wilson 2013) it is important to determine whether such programmes live up to this expectation. Such insights help us understand why professional development programmes do or do not lead to the desired on-the-ground responses and actions in educational practice (e.g., Coburn 2004, Hubers *et al.* 2017, McLaughlin and Mitra 2001, Spillane 2000, Wolthuis *et al.* 2020). From a practical point of view, such information is critical for refining a professional development programme, optimising its effectiveness, and making an informed decision on whether it is worth a continued investment of effort and resources (Coburn and Turner 2011, Hubers 2016).

Therefore, the present study aims to contribute by studying the design of professional development programmes for science and technology education. First, activities or factors that are essential in facilitating educators' professional development are identified, specifically with regard to providing science and technology education. Second, the presence of such activities and factors in current professional development programmes is investigated.

Theoretical framework

Science and technology education

Although science and technology represent two different domains, they are highly connected to each other (Constantinou *et al.* 2010). Related to science, Constantinou *et al.* (2010, p. 145) stated that: '[It] aims at producing reliable knowledge about how systems function.' Consequently, the primary goal of science education is that students learn not only about how science works but also about the explanations of the material world that science offers (Osborne and Dillon 2008).

In contrast, technology 'seeks to generate solutions to problems encountered by society or to develop procedures or products that meet human needs (Constantinou *et al.* 2010, p. 145). The primary goal of technology education is to develop students' technological literacy, meaning that students understand the relation between objects' form and functionality, have a broad understanding of how and why things (including technological products, systems, and trends) work and are developed, and are able to design and evaluate their own technological solutions (Compton *et al.* 2011, Technology in the NZC 2016, Jablansky *et al.* 2019). Therefore, a key aspect of the technology curriculum is to give students opportunities to interact with and learn about a variety of technological objects through physical manipulation and conversations with teachers and peers.

Although science and technology represent two different domains, in the Netherlands, where this study was conducted, the science and technology domains are integrated into one subject: science and technology education. Therefore, this article will focus especially on this combination of subject matters, although the domains might be provided separately in other educational systems. In teaching science and technology content in such an integrated manner, various pedagogies can be used, including inquiry science instruction, problem-based instruction and context-based and science-technology-society approaches (e.g., Bennett *et al.* 2007, Walker and Leary 2009, Furtak *et al.* 2012, Van Uum *et al.* 2016). For example, when teachers use an inquiry-based approach, they need to guide students through the seven inquiry phases (Van Uum *et al.* 2016). This includes, amongst other things, questioning students to prompt them to retrieve their prior knowledge and improve their understanding (exploration), and scaffolding the procedures of formulating a research question and setting up a proper research design (designing the investigation).

The Dutch context

The present study was conducted in the Netherlands. Similar to what is seen in other countries, Dutch primary and secondary school teachers are struggling to implement science and technology education in their daily practice. For example, a scouting committee found that Dutch teachers pay relatively little attention to science and technology education and have little idea of what the domains of science and technology entail (Verkenningscommissie 2013). Moreover, the committee reported that teachers have little attraction to these domains and do not feel able to provide this type of educational content. In spite of the attention that has been paid to assist educators in embedding science and technology content within the current curriculum, schools, on average, devote very little time and attention to this subject (Kneepkens *et al.* 2011). This is likely to be caused by various factors. For example, 22% of Dutch teachers in primary education have low self-esteem when it comes to using experiments to explain scientific concepts (Meelissen and Punter 2016). Moreover, Dutch teachers usually display little attraction to science and technology (Van Aalderen-Smeets *et al.* 2012). Their professional development might be a key strategy for successfully implementing science and technology education in primary and secondary education.

Teachers' professional development

Teacher learning is deemed critical for changing teachers' instructional practices (Sleegers and Leitwood 2010). This is why professional development programmes are often used to bring about school improvement, especially within the domain of science and technology education (e.g., Sandholtz *et al.* 2019).

Professional development programmes are 'systematic efforts to bring about change in the classroom practices of teachers, in their attitudes and beliefs, and in the learning outcomes of students' (Guskey 2002, p. 381). Numerous programmes have been developed to aid teachers' professional development regarding science and technology education (e.g., Akerson *et al.* 2009, Berry *et al.* 2009, Van der Valk and De Jong 2009, Banerjee 2010). For example, such programmes have focused on the use of scientific modelling to improve teachers' views of the nature of science and inquiry (Akerson *et al.* 2009), or have used a reflective approach to aid teachers and elicit rich insights into their teaching and their students' learning of science (Berry *et al.* 2009).

Although previous research has determined the characteristics of effective teacher professional development in general, or addressed the characteristics of professional development specifically addressing science and technology education, a merger between the two has not yet been made. Moreover, it is important to determine whether professional development programmes actually incorporate such characteristics in order to establish whether such programmes are meeting the high expectations that are held for them. Therefore, the present study poses the following research questions:

(1) What does previous research teach us about design features that enhance the chances of teacher professional development successfully enabling teachers to provide science and technology education?
(2) To what extent and how do four Dutch professional development programmes for science and technology education incorporate these design features?

Method

Context

The present qualitative study took place in the Netherlands, where society faces an increasing shortage of highly educated, technical employees. This poses serious threats to Dutch competitiveness and opportunities for economic growth (Government of the Netherlands 2013). Consequently, science and technology education receives nationwide attention. Dutch schools have considerable freedom in determining what subject matter they teach, what textbooks, assessments and instructional strategies they use, and the religious or ideological beliefs to which they adhere (Ministry of Education, Culture and Science 2000, Kuiper *et al.* 2006). As far as the implementation of science and technology education, this means that schools have considerable freedom to implement instruction of this content in a way they see fit. The nationwide goal is that all primary schools will integrate science and technology education into their curriculum and that in secondary education, more students will choose science related courses (Nationaal Techniekpact 2018).

Part 1: review of effective characteristics

In order to provide solid characteristics of successful professional development programmes, we used review studies and meta-analyses that undergone the peer-review process or that were associated with large-scale government-funded projects. Only studies published after the year 2000 were included. In total, four studies were included that provided conclusions specifically for science and technology education (Van Driel *et al.* 2001, 2012, Higgins and Spitulnik 2008, Gerard *et al.* 2011), and seven studies were used that studied teachers' professional development programmes for a variety of subject matters (Desimone 2002, Timperley *et al.* 2007, Gegenfurtner 2011, Postholm 2012, Dogan *et al.* 2016, Kennedy 2016, Maandag *et al.* 2017). The steps taken to analyse these studies and synthesise their findings are described at the end of this section.

Part 2: applying the characteristics to professional development programmes

Four Dutch professional development programmes related to science and technology education were selected for evaluation; see Table 1. These programmes were selected because they were (co-) designed by principal investigators holding a doctoral degree in a psychology or education related field. It was assumed that such programmes would give us the best idea of whether and how the characteristics of effective professional development programmes are being implemented. In addition, multiple schools were working with these programmes. Those schools were in the final stages of the programme or had already finished working with the programme. That meant that we could ensure that the design of these professional development programmes was definitive, at least for this round of schooling. Each principal investigators was the (co-)designer of one the four professional development programmes. They were interviewed in order to get a better idea of the reasoning behind the programmes. In addition, for three out of the four programmes, a school leader and one or more teachers were interviewed. The educators who worked with the fourth programme did not want to participate in the current study.

Table 1. Description of professional development programmes and interviewees.

		Programme A	Programme B	Programme C	Programme D
Professional development programme	Aim	Integrating language education with science and technology education	Stimulating student citizenship in relation to science and technology issues	Developing a career counselling programme with an emphasis on science and technology	Student talent development via science and technology
	Example of activity	Teachers watch a video of a lesson together and determine what the goal of that lesson was, what steps students need to make in their reasoning, and what language goals should go with those steps.	During this programme, teachers learn to design their own lesson cycle. One of the activities is to determine students' learning goals.		Teachers keep a 'wonderment diary' for 1 week.
	Target audience	Primary education	Primary and secondary education	Secondary education	Primary education
	Effectiveness	The researcher collected data about teachers' ($N \approx 18$) self-efficacy and log files of their reported activities. However, these data have not yet been analysed.	The participating teachers (($N \approx 22$) self-reported that they achieved their goals. Other questionnaire data were collected as well, but have not yet been analysed.	The effectiveness of this programme has not yet been determined by the researcher.	The programme led to a significant increase in teachers' positive attitudes towards science and technology education ($N \approx 600$).
Interviewees		investigator	dr. Archer	dr. Banks	dr. Clarkson
	Principal	dr. Davidson			
	Educators	No educators participated	Ms. Bell (teacher 6th grade) Mr. Burke (teacher 5th grade) Ms. Branson (school leader)	Mr. Collins (dean and teacher of 'Man and nature' course) Ms. Carter (school leader)	Mr. Dudley (school leader) Ms. Durand (support coordinator)

Instruments – professional development materials

All principal investigators were asked to send the professional development materials for their programmes. This included manuals, PowerPoint slides, and worksheets.

Instruments – interviews

All principal investigators were interviewed individually; the school leaders and teachers were interviewed per school in groups of 2–3. Thus, seven interviews were conducted. The interviews had an average duration of 60 minutes, and covered a range of topics including their experiences with the professional development programme and the factors promoting and hindering educational change.

Data analysis parts 1 and 2

First, the conclusions of the review studies and meta-analyses were summarised and synthesised. If a characteristic appeared in more than one study, it was used in the synthesis of effective characteristics. Second, the resulting list of characteristics was translated into a coding scheme, see Table 2.

The interviews were conducted and member checks were used to ensure the validity of our summary of the interviews. Subsequently, the coding scheme was applied to the interviews and the professional development materials. Regarding the latter, a code was applied when the corresponding characteristic was explicitly mentioned in the manual. The reason for this is that it is assumed that when teachers continue to work on improving their science and technology education they are likely to consult their manual. If important characteristics, for example, taking the role of the school context into account, are not addressed in that manual, it becomes less likely that teachers will be aware of the role such characteristics play and are less likely to take them into account.

After coding the data, our findings for each of the characteristics were summarised per programme and compared and contrasted, which facilitated within-case and cross-case analyses. The interviews helped triangulate our findings from the professional development materials, which

Table 2. Coding Scheme.

	Characteristic	Definition
Content	Focus	The programme emphasises teachers' pedagogical content knowledge in relation to science and technology education. Moreover, attention is paid to students' learning processes within this domain. Specific benchmarks or standards could be mentioned, though this is not required.
	Activities	Teachers play an active role in the professional development programme. This means that concrete activities, such as teaching, assessment, observations, reflections, or students' learning processes play a central role. Receiving feedback is also part of this characteristic. It is especially beneficial if teachers reflect on whether students increased their knowledge and/or in what way they gained insights. If new technologies play a role, it would be best if the way in which they should be used in the classroom is described clearly.
	Collaboration	The programme explicitly discusses and uses collaboration between colleagues (from the same school, group, and/or the same course, or experts from a different school). Different types of collaboration are possible, for example, discussing science and technology education in general, or observing and discussing each other's lessons.
	Coherence of content	The programme is consistent in terms of the (learning) goals that are being proposed and the corresponding content of the programme.
	Duration	The programme has multiple meetings and follow-up meetings. The number of meetings has to be fitting for the type of content that is being provided
Context	Coherence with context	The programme explicitly connects with the goals and the policy of the school.
	Organisational factors	The programme explicitly takes into account organisational factors at the school that could influence the working of the programme. Examples include: resources, facilities and support from school leaders.
	Individual factors	The programme explicitly takes into account factors involving individual differences among the participating educators. Examples include: differences in personality, attitudes, and/or competences.

ensured the construct validity of our findings (Yin 2003). Quotes from the interviews and the professional development materials were translated from Dutch into English to illustrate the results.

An audit procedure was used to ascertain transparency and reliability with regard to all aspects of the data analysis (Akkerman *et al.* 2008). The first author provided an audit trail, which includes a detailed description of the data and of all steps and procedures followed in the analysis (Poortman and Schildkamp 2012). The third author used this trail to perform the audit. Agreement was reached for all analytical steps, so that the results are transparently and reliably grounded in the data.

Results

First, this study determined what previous research has shown to be the design features that enhance the chances of successful professional development of primary and secondary education teachers to help them provide science and technology education. Overall, nine characteristics were distinguished that appeared critical in supporting the effectiveness of professional development activities, see also Table 3. Roughly, these characteristics can be divided into two groups: characteristics related to the content of the programme (focus, activities, collaboration, coherence of content, and duration) and characteristics related to the context in which the programme is implemented (coherence with context, organisational factors and individual factors).

Second, this study determined to what extent and how the four professional development programmes that were investigated incorporated these characteristics. Below, for each characteristic, a description is provided of what previous research had to say about it, and how it was used in the four professional development programmes. These results are also summarised in Table 4.

Characteristics of content

Focus
The first characteristic is that a professional development programme should focus on teachers' classroom practice (Van Driel *et al.* 2001, 2012, Desimone 2002, Timperley *et al.* 2007, Higgins and Spitulnik 2008, Kennedy 2016, Maandag *et al.* 2017). This means that teachers' pedagogical content knowledge is addressed, so that they have the required knowledge and skills to teach a certain content area. However, focusing exclusively on content knowledge is likely to have less effect on student learning (Kennedy 2016). It also appeared important to address students' learning processes within that content area. Finally, the specificity of the design also matters, in that specific designs (e.g., including benchmarks, guidelines and standards) are helpful for educators to measure students' progress (Desimone 2002). However, Desimone also found that the more specific the design, the less creativity it requires from the teachers to implement a change. It is not yet known where exactly the balance between these lies.

The analysis showed that the characteristic of focus was absent in all four of the professional development programmes. This means that teachers' pedagogical content knowledge about science and technology was not addressed, although programme D did provide some resources that teachers could consult if necessary. Moreover, none of the programmes explicitly addressed student learning processes related to science and technology education. However, three principal investigators mentioned that they aimed to focus on teachers' classroom practice. But dr. Banks, the principal investigator of programme B, also admitted that, although they discussed during the programme how the lesson cycle should be implemented in their everyday practice, teachers struggled to do so and should have been provided with additional support. Moreover, the principal investigators struggled to specify when teachers had mastered the content of the PD program. For example, when dr. Clarkson, principal investigator of programme C, was asked when a teacher takes on a good coaching role in facilitating career counselling, she answered: '*Yes, answer that . . . That's very difficult to determine.*'

Table 3. Overview of characteristics and the studies in which they appeared.

	Content					Context		
	Focus	Activities	Collaboration	Coherence of content	Duration	Coherence with context	Organisational factors	Individual factors
Professional development in general								
Desimone 2002	X					X	X	X
Dogan et al. 2016			X					
Gegenfurtner 2011			X					X
Kennedy 2016	X	X			X			
Maandag et al. 2017	X	X	X				X	X
Postholm 2012	X	X	X		X	X	X	X
Timperley et al. 2007	X	X	X	X	X	X	X	
Professional development for S&T education								
Gerard et al. 2011	X	X	X		X	X	X	
Higgins and Spitulnik 2008	X	X	X		X			
Van Driel et al. 2001	X		X		X			
Van Driel et al. 2012	X	X	X	X	X	X	X	

Table 4. Overview of characteristics of effective teacher professional development programmes and their presence in four programmes for implementing science and technology education.

		Programme A	Programme B	Programme C	Programme D
Content	Focus	- There is no focus on developing knowledge of S&T content and pedagogy. Little attention is given to students' learning processes and no connection is made with teachers' current experiences.	- There is no focus on developing knowledge of S&T content and pedagogy. Little attention is given to students' learning processes and no connection is made with teachers' current experiences.	- There is no focus on developing knowledge of S&T content and pedagogy. Moreover, there is no focus on students' learning processes.	- There is no focus on developing knowledge of S&T content and pedagogy, though resources are provided that teachers can use to learn such content. Little attention is given to students' learning processes and no connection is made with teachers' current experiences.
	Activities	-/+ Several activities are included. However, it is not made explicit how teachers can find evidence of student learning. Receiving feedback is optional.	-/+ Though teachers play an active role in the design teams, they do not receive a lot of support in their design activities (e.g., what would be a good activity for students?). Video coaching is provided, but no information is available the way in which it is used.	-/+ Teachers design their own programme for career guidance, though it is unclear how they can support their students in the right way.	-/+ Several activities are included. However, it is not made explicit how teachers can find evidence for student learning. The role of feedback is not mentioned.
	Collaboration	- Some exercises need to be done with a colleague, though no clear goal for collaboration is stated.	- Teachers work together during the design cycle, but the role of collaboration is not made explicit.	- Teachers work together during the design cycle, but the role of collaboration is not made explicit.	- Some exercises need to be done with a colleague, though no clear goal for collaboration is stated.
	Coherence in content	- The characteristics of a good lesson are addressed, but teachers do not learn how to actually give such a lesson.	- The goal is to implement and evaluate a lesson cycle. However, the programme seems to be especially focused on designing this lesson cycle.	- The goals are that students should get better insights into their ambitions, learn how to self-regulate themselves and develop a more positive attitude towards technology. Although general conversation techniques are discussed, these three goals are not addressed.	- Several competencies are mentioned that reflect the core of this programme. However, the activities used do not address these competencies. The activities aim to facilitate teachers' own experience (e.g., with posing curiosity-based questions), but how they should encourage their own students to pose such questions is not addressed.
	Duration	+ 6 meetings of 3 hours each, spread out over 6 months. Follow-up meetings are mentioned.	-/+ 4 meetings of 2 hours each, spread out over 2 months. In addition, monthly video coaching sessions were scheduled. Follow-up support is not mentioned.	+ 6 meetings of 2–2.5 hours each, spread out over 4 months. Follow-up meetings are mentioned.	-/+ 6 meetings of 3 hours each, spread out over 6 months. Follow-up support is not mentioned.

(Continued)

Table 4. (Continued).

		Programme A	Programme B	Programme C	Programme D
Context	Coherence with context	- No attention is paid to this characteristic.	- One brief activity was included during which teachers determined how this programme matches their school's vision.	- One brief activity was included during which teachers determined what kind of policy initiatives are present in the school and how they can match these initiatives.	- No attention is paid to this characteristic.
	Organisational factors	- No attention is paid to this characteristic.	- The manual briefly mentions once to adapt the learning goals for students to their specific student population.	+ This programme aims to fully adapt to the school context.	- No attention is paid to this characteristic.
	Individual factors	- No attention is paid to this characteristic.	- No attention is paid to this characteristic.	- Teachers are asked once to individually think about what kind of outcomes they would like to achieve.	- No attention is paid to this characteristic.

Signals that this characteristic is not explicitly addressed in the professional development materials, -/+ signals that this characteristic is somewhat present, but not in the way indicated as effective by previous research, + signals that this characteristic is present in the professional development materials in the way indicated as effective by previous research.

Activities

The second characteristic is that teachers should play an active role during the professional development programme (Gerard *et al.* 2011, Timperley *et al.* 2007, Higgins and Spitulnik 2008, Van Driel *et al.* 2012, Kennedy 2016, Maandag *et al.* 2017). This will enhance teachers' perceived relevance and usefulness of the programme in connection with their daily work (Van Driel *et al.* 2012). Various activities can be used, including: receiving feedback, observing expert teachers, being observed by other teachers, practicing new ways of teaching, discussing elements of the change with others and reviewing student work. A specific recommendation for the domain of science and technology education was that the activities need to guide teachers, especially in reflecting on and integrating their ideas (Gerard *et al.* 2011). Moreover, it is crucial that the activities support teachers in gathering insight into students' ideas and evidence of students' progress in developing understanding of the course material. These activities need to explicitly support teachers in reflecting on evidence of student learning. Finally, a professional development programme needs to address the use of new technology, as teachers appeared to lack the time and expertise to plan for this by themselves (Gerard *et al.* 2011).

In all four programmes, teachers played a relatively active role. Examples of activities included thinking about one's definition of science and technology and one's attitude towards both (programme D), and using a lesson plan form to describe a videotaped lesson by a teacher who is not part of the programme (programme A). Teachers played an especially active role in programmes B and C, where teachers designed their own lesson cycle and programme for career counselling respectively. However, none of the activities in the four programmes made explicit how teachers can gather evidence of student learning. Overall, receiving feedback did not have a strategic place in these four programmes, either because it was not specified or was under-specified, or because teachers needed to 'opt in' to receive feedback. Taken together, the findings signal that this characteristic was somewhat present in the programmes, but not yet in the way indicated as effective by previous research

Overall, the principal investigators tried to be evidence-informed in their selection of activities. For example, dr. Archer, the principal investigator of programme A, included activities that teachers appreciate, according to research by Bakkenes *et al.* (2010). Other principles that were used in the programmes were scaffolding and addressing teachers' zone of proximal development.

Collaboration

Our synthesis of the findings of the review studies determined that facilitating and stimulating collaboration within a professional development programme is likely to be beneficial for teachers' professional development (Desimone 2002, Dogan *et al.* 2016, Gerard *et al.* 2011, Kennedy 2016, Higgins and Spitulnik 2008, Maandag *et al.* 2017, Timperley *et al.* 2007, Van Driel *et al.* 2001, 2012). This can take shape through mentoring or collaboration between teachers from the same school, grade or subject, or cross-organisational collaboration. Amongst other things, collaboration can be a powerful way to help teachers articulate their own practices, add new ideas, reflect on their practice and to provide them with permanent access to colleagues' expertise (Gerard *et al.* 2011, Van Driel *et al.* 2012).

In all four programmes, teachers had to collaborate with each other during activities. This was especially the case in programmes B and C, where groups of teachers designed their own lesson cycle and programme for career counselling, respectively. However, the role of collaboration was not explicitly addressed in any of the programmes. For example, programme A included the activity: '*Discuss the form with your lesson plan on it with one of your colleagues who does not participate in this programme.*' In such activities, there was no explicit reference to what should be gained by this collaboration or how collaborating could take shape to make it most effective. Overall, it was determined that these four programmes were not explicitly designed in a way that benefits from collaboration between educators.

Coherence of content

This characteristic refers to the coherence between the goals of the professional development programme and its design (Timperley *et al.* 2007, Van Driel *et al.* 2012). This requires that the designers of the professional development programme understand the way in which specific features of the programme address the intended learning goals. This could be done, for example, through formulating a theory of improvement.

Clear coherence of content could not be distinguished in any of the four programmes. Each programme set out goals that were difficult to translate to the activities that were used, that presumably should address these goals. For example, the manual of programme D stated that its most important goal was to stimulate students' talent development within the domain of science and technology. However, all activities were initially aimed at letting the teacher experience for him/herself something related to science and technology (e.g., asking yourself curiosity-based questions), after which they needed to facilitate that activity for their students. They did not receive explicit guidance in how to do so. Moreover, the development of students' talents, except when stating the goal of the programme, was not mentioned in the manual and no activities were included that explicitly addressed this.

The gap in coherence of the programmes was also found during the interviews, during which the principal investigators were asked what the goal of their programme was. Two of them mentioned the same goal as mentioned in their programme manual, which did not appear to match the activities chosen, and two of them mentioned a goal that did match those activities but was different from the goal mentioned in the manual. Sometimes, this gap in coherence was noticed by the participants. For example, Mr. Burke mentioned that the programme facilitators did not always agree with each other about the quality that was required in teachers' lesson designs.

Duration

This characteristic refers to the substantial amount of time, meaning the time span over which the professional development and follow-up activities take place and the number of hours spent on professional development, that is required to stimulate teachers' professional development (Gerard *et al.* 2011, Higgins and Spitulnik 2008, Kennedy 2016, Timperley *et al.* 2007, Van Driel *et al.* 2001, 2012). However, receiving extended opportunities for professional development was not always related to a positive impact on student outcomes (e.g., Timperley *et al.* 2007). Especially when the message of the professional development programme was prescriptive, a longer programme duration was less effective (Kennedy 2016). No minimum number of hours could be established (Van Driel *et al.* 2012), and it appeared that how time was used seemed to be more important than the amount of time (Timperley *et al.* 2007).

All four professional development programmes under study paid attention to the duration of the programme to some extent. Four to six meetings were scheduled, each with a duration of a few hours. Moreover, these meetings took place over two to six months. Programmes A and C also provided follow-up support, which signals that this characteristic is present in both programmes in the way indicated as effective by previous research.

Context characteristics

Coherence with context

This characteristic refers to the extent to which the professional development programme matches school, district and state reforms and policies (Desimone 2002, Postholm 2012, Timperley 2007, Van Driel *et al.* 2012). If this consistency with the context is missing, the professional development programme could be perceived by educators as an isolated or even an irrelevant endeavour.

The analysis of the professional development programmes showed that hardly any explicit attention was paid to coherence with context. In programmes B and C, only one brief activity was undertaken with teachers in which they had to think about how their participation in the

professional development programme was related to the school's vision about science and technology education.

During the interviews, the principal investigators did not address the importance of coherence with context. In contrast, all interviewees from educational practice highlighted its importance. For example, Ms. Durand, who participated in programme D, said: '*He {the trainer} did not know his target audience who were in the room. We are all people who think critically about the education we provide. It was a standard programme that will probably be taught that way in every school. In a lot of schools, that will work, but not here. Everyone was sitting there like: I'm not a standard school, we already do things differently from others.*'

Organisational factors

A plethora of organisational factors appeared to influence the effectiveness of professional development programmes (Desimone 2002, Maandag *et al.* 2017, Postholm 2012, Timperley *et al.* 2007, Van Driel *et al.* 2012). Examples included the available resources and facilities, support by the school leaders, the physical characteristics of the school, external factors and the school culture. However, although such factors should be taken into account in the design of a programme, how this should be done was not yet known.

Three out of the four programmes did not pay any attention to the role of organisational factors. Moreover, with regard to programme D, it was mentioned in the manual that:

> *A teacher could feel that he or she is dependent on a good teaching method, money, materials, or support of colleagues in order to provide a good science and technology lesson. However, in this programme, it is not about whether or not such teaching methods, money, etc., are available, but whether the teacher <u>feels dependent</u> on these things. These two factors, namely self-efficacy and the feeling of dependence on external factors, determine the extent to which someone feels 'in control' of providing science and technology education.*

Thus, in programme D the role of organisational factors seemed to be played down. The only programme that adapted its content fully to the organisational factors was programme C. This was also noticed by the participants. For example, Mr. Collins, who participated in programme C, indicated that the way in which the programme took the organisational factors at his school into account was one of the strongest points of this programme. For example, one of the central activities in this programme was that teachers needed to answer these questions about the current situation in their school: '*What is going well? What do we want to keep? What needs to improve? And how can we relate this to our career counselling conversations?*'

Although three out of the four programmes did not pay any attention to the role of organisational factors, all principal investigators indicated awareness that such factors play a crucial role in whether or not teachers will make changes in their daily practice. The factors most often mentioned included time, money and the role of the school leader. The teachers and school leaders who were interviewed added to those factors the role of colleagues. For example, at the school that was working with programme D, there is a special teacher for science and technology education. '*She has a lot of affinity with this topic and she infects us,*' support coordinator Ms. Durand explained.

Individual factors

Similar to the organisational factors, there was also a plethora of individual factors that influence the effectiveness of professional development (Desimone 2002, Gegenfurther 2011, Maandag *et al.* 2017, Postholm 2012). Examples included teachers' motivation, personality, competencies, and teaching expertise. Here, too, the best way to take these factors into account was not yet known. However, some authors suggested that, for example, teachers should propose their own learning goals within professional development programmes (Maandag *et al.* 2017).

The analysis of the professional development programmes showed that no explicit attention was paid to the individual factors. However, the principal investigators did mention individual

differences between teachers. For example, dr. Davidson, principal investigator of programme D, mentioned that factors such as educational degree, flexibility and creativity play a role.

Discussion

As teachers' continuous professional development remains to be seen as one of the most important driving factors for improved science and technology education (Osborne and Dillon 2008, Wilson 2013) it is important to determine whether such programmes live up to this expectation. This study contributed by focusing on the design of professional development programmes. First, the essential characteristics of such programmes for facilitating educators' professional development were determined, specifically for providing science and technology education. Second, how such characteristics are present in four professional development programmes for science and technology education was studied.

Essential characteristics of professional development programmes

In total, eleven review and meta-analytic studies were used to identify the essential characteristics of professional development programmes, see also Table 3. This resulted into a list of nine characteristics that could roughly be classified as characteristics of content and context. Regarding the former, the first characteristic is a focus on pedagogical knowledge about science and technology as well as a focus on student learning processes. Second, activities need to be included through which teachers can engage in active learning. Third, collaboration with colleagues and school leaders needs to be facilitated. Fourth, a programme needs to have coherent content. This means that its learning goals match the designed activities. The last content characteristic is the duration of the programme. This means that a sufficient number of hours needs to be spent on professional development within a suitable time span, though previous research did not identify an exact guideline for this.

In addition, three characteristics related to the context were distinguished. The first is coherence with the school context, in that the programme explicitly tries to establish alignment with schools' goals and policies. The second characteristic is that the programme should address the participating school's organisational factors. The final characteristic is that the programme should address the participating teachers' individual difference factors.

Presence of characteristics in professional development programmes

In total, four professional development programmes that aimed to address teachers' implementation of science and technology education were studied. Overall, it appeared that the programmes were relatively similar in their design, in that they incorporated the characteristics in a relatively similar manner or left the same characteristics out.

The characteristic coherence with context was fully addressed within one programme. Within this programme, teachers designed their own guide for providing career counselling to their students. In all of their activities, they had to take their own school context (e.g., available time and resources) into account. The characteristic duration of the programme was fully addressed by two programmes and partly addressed within the other two. All four programmes had scheduled several meetings over a period of two to six months. Moreover, two of the programmes also scheduled follow-up meetings.

The characteristic activities was somewhat present in all four programmes in that all four programmes included a variety of activities that enabled active participation from the teachers. However, the critical activity of determining how teachers can find evidence for student learning was missing, and feedback to teachers did not have a strategic place in these four programmes. This is in line with Rogers *et al.* (2007), who found that facilitators of professional development

programmes for teachers did not have student learning processes in mind when defining effective professional development programmes. However, the absence of such activities is quite problematic, because teachers need such insight into students' learning processes in order to learn themselves from their own teaching practice (Gerard *et al.* 2011). For example, these insights are required to identify specific areas that students struggle with, to reflect on potential problems in the instruction teachers have provided, and to generate refined strategies to improve student understanding. In the end, whether or not teachers have gained insight into efficient procedures that assist them in their everyday teaching practice is one of the most important determinants of teachers' commitment to implement an innovation (Doyle and Ponder 1977, Spillane *et al.* 2002).

All other characteristics, meaning focus, collaboration, coherence of content, coherence with context and individual factors were hardly addressed or not addressed at all in all four programmes. Three out of the four programmes also did not pay any attention to the organisational factors that could play a role. The absence of focus on teachers' pedagogical content knowledge of science and technology and students' learning processes related to this content seems especially striking. Although all four primary investigators had expertise related to and relevant for science and technology education, only one of them had a background in science pedagogy, which might explain the absence of attention to this characteristic. It was not yet clear why these primary investigators did not yet pay attention to various characteristics of effective professional development programmes. One possible explanation for this could be that the primary investigators did not yet have a clear end goal in mind of what they wanted to achieve with their professional development programme. For example, none of the primary researchers could give a concrete description of when they would be satisfied with the participating teachers' implementation of science and technology education. This description included ambiguities such as that 'something' is being done with science and technology, or that a general standard should not be imposed but individual goals should be (though what these were remained unclear). Moreover, researchers have different conceptions on what good science education research is (Fensham 2004), which might influence the design decisions they make when setting up their study and corresponding professional development programme. Additional systematic research is required to dive deeper into this issue.

Although two out of four researchers indicated that there was some positive evidence for the effectiveness of their programme, see Table 1, both relied on self-reported data. Moreover, data about the other two programmes were not yet analysed or collected. Therefore, it would be premature to make statements about the current effectiveness of the four programmes. However, the results of this study show that there are likely to be areas for development in the design of these professional development programmes for science and technology education. Moreover, as these programmes were all designed by primary investigators with a doctoral degree and expertise within or related to the domain of educational science, having experts design such programmes is not a panacea. If their programmes do not fully incorporate all characteristics of effective professional development, it could be that such areas for improvement can be spotted across all kinds of professional development programmes.

Unfortunately, this is not the first study to signal such areas for development in the design of professional development programmes. Other studies have confirmed either problems with the design itself (e.g., Hourani and Stringer 2015), or how the design unfolded in practice (e.g., Collins and Liang 2015, Saderholm *et al.* 2017). Although why it is challenging to design effective professional development programmes has not been studied, a possible explanation might be that principal investigators systematically underestimate the complexity of educators' everyday practice, which could translate into the design of their programme. Kennedy (2010) calls this underestimation a fundamental attribution error, and her work, as well as that of Doyle (2006), gives an impression of all that is going on in everyday practice, of which change is just one element.

Implications

Although teacher learning, especially via formal professional development programmes, has been deemed critical for changing teachers' instructional practices (Sleegers and Leithwood 2010), the present study illustrated that such programmes might not live up to this expectation. Such insights help us understand why professional development programmes often do not lead to the desired on-the-ground responses and actions in educational practice (e.g., Coburn 2004, Maandag *et al.*2017, McLaughlin and Mitra 2001, Spillane 2000, Hubers, accepted for publication). In turn, improving the design of professional development programmes could be a key strategy to address the sustainability challenge.

From a practical perspective, this study shows that there might be a lot to gain in the design of professional development programmes. As such programmes are often used to attain school improvement, especially for science and technology education (e.g., Sandholtz *et al.* 2019; Van Driel *et al.* 2012), it is crucial that improvements be made. In addition, this work signals the importance of educators being critical consumers of professional development programmes: they need to be aware of how they can spot whether a professional development programme is likely to be effective for them. This means, for example, asking how it will adapt to their own school context. Similar to what was recommended by Schachter *et al.* (2019), guidelines to assist schools in selecting professional development programmes might be of value.

Limitations

The present study had a few limitations. The first one is that only four programmes were studied, which means that the generalisability of our findings might be limited. However, the findings do illustrate that there might be a world to gain in designing effective professional development programmes.

The second limitation is that we did not observe how trainers and coaches addressed the content of the professional development programmes. Therefore, it could be that additional activities were conducted or additional explanations were given to teachers that could have increased the effectiveness of the programme. However, this study is grounded in the assumption that when teachers continue to work on improving their science and technology education they are likely to consult their manual. If important characteristics, for example, taking the role of the school context into account, are not addressed in that manual, it becomes less likely that teachers will be aware of the role such characteristics play and are less likely to take them into account.

Suggestions for future research

Although it might be insightful to learn more about the extent to which professional development programmes do (not) address the characteristics identified here, it might be most helpful to enable further development of the design of such programmes. In doing so, the framework for sustainable educational change could be taken as a point of departure (Hubers, accepted for publication). In that way, work can start from an overarching theory the way in which learning and changing should be addressed in professional development programmes, which is currently lacking (Muijs *et al.* 2014, Kennedy 2016).

Such a design-oriented approach might want to cast a wider net than just formal activities, as teachers also learn explicitly and implicitly in and from their everyday practice (Eraut 2000, Horn and Little 2010, Little 2012). Moreover, the knowledge gaps related to the role of the school context need to be addressed (Sleegers and Leithwood 2010). This means that we need to understand why change works, for whom it works and in what context it works (Cohen and Meta 2017, Hubers, accepted for publication, Pawson and Tilley 1997). There are several approaches to cover such

a perspective, including 'theories of change' and 'realistic evaluation' (Pawson and Tilley 1997, see Blamey and Mackenzie 2007, for a comparison between the two approaches).

Overall, this study illustrated that there is a lot of room for improvement in the design of professional development programmes that are intended to support and enhance science and technology education. If such improvements are made, an important step towards sustainable educational change has been taken.

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