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Designing a Data Feedback Program to Improve Teachers' Science and Technology Teaching Skills in Elementary Education

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Abstract

In this study, a data feedback program to improve teachers' science and technology (S&T) teaching skills was designed and tested. The aim was to understand whether and how the four design principles underlying this program stimulated the intended teacher support. We examined how teachers in different phases of their career applied and experienced the employed design principles' key aspects. Eight in-service teachers and eight pre-service teachers attended the data feedback program and kept a logbook in the meantime. Group interviews were held afterwards. Findings show that applying the four employed design principles' key aspects did support and stimulate in- and pre-service teachers in carrying out data feedback for improving their S&T teaching. However, some key aspects were not applied and/or experienced as intended by all attending teachers. The findings provide possible implications for the development and implementation of professional development programs to support in - and pre-service teachers' S&T teaching using data feedback.

Keywords: data feedback, design principles, inquiry-based science education, science and technology, teaching skills.

1. Introduction

An appropriate Professional Development Program (PDP) to support elementary school teachers in teaching Science and Technology (S&T) is strongly needed [1,2]. In response, a number of studies present a PDP equipping elementary teachers to teach Science and Technology (S&T) with greater confidence and expert knowledge [3-6]. These studies detail how teachers experience the design principles underlying the presented PDPs and thereby enabling them to improve their teaching. Yet, for tailoring PDPs such that these are useful in different contexts and for a variety of teachers, it is also important to examine how teachers apply specific key aspects of the design principles underlying the PDPs. Knowledge based on such research is required to make grounded adjustments to a PDP and enhance its implementation [7,8].

Recent PDPs to improve teachers' S&T teaching (as mentioned above) focus on teaching about S&T through inquiry, signifying that pupils develop inquiry skills and an understanding about S&T topics through experimentation, interpretation and discussion of inquiry-driven results [9]. This approach of S&T teaching and learning is referred to as Inquiry Based Science Education (IBSE), or guided IBSE if teachers guide their pupils in the inquiry process by raising a central driving question [10,11].

Our study focuses on adjusting and optimizing a PDP on S&T teaching in Dutch elementary education. In contrast to the Next Generation Science Standards in the USA, there are no national standards for S&T pertaining to Dutch elementary schools. Although Dutch elementary schools are legally required to have S&T education implemented in the curriculum, only broad-based guidelines regarding the teaching approach to be followed (i.e. inquiry-based learning) have been provided. To stimulate the development of S&T education in elementary schools, the government encourages universities to cooperate with elementary schools to foster teachers' professionalization.

The current study partly builds on the results of our previous study, a study piloting a PDP in which Dutch pre-service teachers (PSTs) improved their pedagogical skills to apply IBSE by completing two data feedback cycles [12]. In a data feedback cycle, teachers systematically collect and analyze data from their own classroom to determine how to adjust their pedagogical skills. Our pilot study showed that PSTs in some cases collected data, enabling them to adjust their pedagogical skills by observing their IBSE lessons and interviewing their pupils after that lesson. However, most PSTs struggled in setting clear personal goals due to insufficient IBSE teaching knowledge. Moreover, PSTs found it difficult to collect, analyze and interpret data with a view to their own learning process, and required support in this regard. Hence, a new PDP has been designed for this study, again based on two cycles of data feedback, with more substantiation of the three previously used design principles in the pilot study and an extra fourth design principle that is likely to provide explicit support to the PSTs (see appendix A for a detailed account of the changes made). This new PDP will be referred to as the data feedback program. The four design principles underlying this program are:
(1) Teachers learn to design and conduct guided IBSE lessons by exploring the IBSE theory and experienced teachers' IBSE practice;

(2) Teachers develop their pedagogical skills by systematically collecting data and reflecting on that data;
(3) Teachers learn from each other's practice (in designing IBSE lessons as well as in inquiring their own practice) in collaborating peer groups;
(4) The teacher educator enacts as a role model for teaching IBSE and collecting, analyzing and interpreting data (The design principles will be more thoroughly discussed in the theoretical framework).

To examine the way teachers in different phases of their career apply and experience the design principles' key aspects of the data feedback program, in-service teachers (ISTs) with varying years of experience and PSTs participated. Although ISTs are more experienced and have more pedagogical knowledge they often have less time and interest in learning new pedagogies than PSTs [13,14]. These differences might influence the teachers' behavior and development in the data feedback program. A significant similarity between the two types of teachers, though, is that regarding the content of a PDP on S&T-teaching, both ISTs and PSTs indicate preference for courses on doing hands-on activities over argument-based science [15].

The aim of this study is to gain a better understanding of whether and how the objectives intended by each of the four design principles underlying the data feedback cycle of this study could be achieved for both ISTs and PSTs. To this end, we examined for each design principle how the participating teachers applied and experienced relevant key aspects of each principle. The research questions are:
(1) How do PSTs and ISTs apply the key aspects of the four design principles while completing two data feedback cycles?
(2) How do PSTs and ISTs experience appling the key aspects of the four design principles?
Answers to these questions may provide clous for a more tailored implementation of PDPs, particularly PDPs aimed at supporting teachers' S&T teaching by means of data feedback.

2. Theoretical Framework

Design Based Research (DBR) aims at theoretical understanding through the (iterative) development of solutions to problems in school practices [16]. The development of curricula and associated changes in teacher behavior is often complex and hard to regulate. DBR facilitates an operating mode in which researchers and teachers (and sometimes other participants as school leaders and/or designers) search for appropriate practices for teaching and learning through intensive collaboration and systematic reflection. DBRs might have different objectives [18,19]; the most common are 1) finding the most appropriate implementation strategies and conditions [19,20] and 2) validating theoretical principles for professional learning in school practice [20,21]. The latter aligns with this study's objective. By examining how PSTs and ISTs apply and experience the key aspects of the principles an endeavor is made to validate the four design principles as they are embedded in the data feedback program (this study's PDP). The theoretical background of the four design principles employed to address the issues that emerged from the pilot study are outlined below.

Design principle 1: Teachers learn to design and conduct guided IBSE lessons by exploring the IBSE theory and experienced teachers' IBSE practice

In guided IBSE lessons, pupils learn about scientific and engineering topics by conducting experiments and discussing this in an ongoing dialogue with each other and their teacher [22-24]. The teacher is the moderator of that dialogue and employs guiding questions aimed at the use of materials (hands-on; for example, 'Can you make the bulb come on with these materials?') and finding evidence-based arguments (minds-on; for example, 'Why doesn't the bulb light up?'). Several studies illustrate which guiding question teachers might ask to support their pupils in developing S&T concepts based on evidence gained in their own hands-on activities [25-27]. These studies also point out that teachers ought to possess certain content knowledge allowing them to ask appropriate guiding questions. For example, a teacher will not be likely to ask the above questions about the light bulb if he/she is unsure as to what the correct answer is.

Prior to implementation, teachers need to design an IBSE-lesson in which pupils are put in a situation that engages them in hands-on activities. The 5E-model [29] offers a structure aiding teacher in designing such IBSE-lesson and has proven to provide adequate situations for guided IBSE [3,30]. This model includes the following phases: engage, explore, explain, elaborate, and evaluate. In the first phase of the 5E-model (engage) the teacher introduces a S&T topic, where after, in the second phase the pupils explore materials related to that topic. In the third phase (explain) the teacher discusses with the pupils what has been discovered during the second phase. Following this discussion, the pupils carry out experiments or observations in small groups (the fourth phase; elaborate). In the fifth phase (evaluate) the pupils present and discuss what they have found during the elaborate phase.

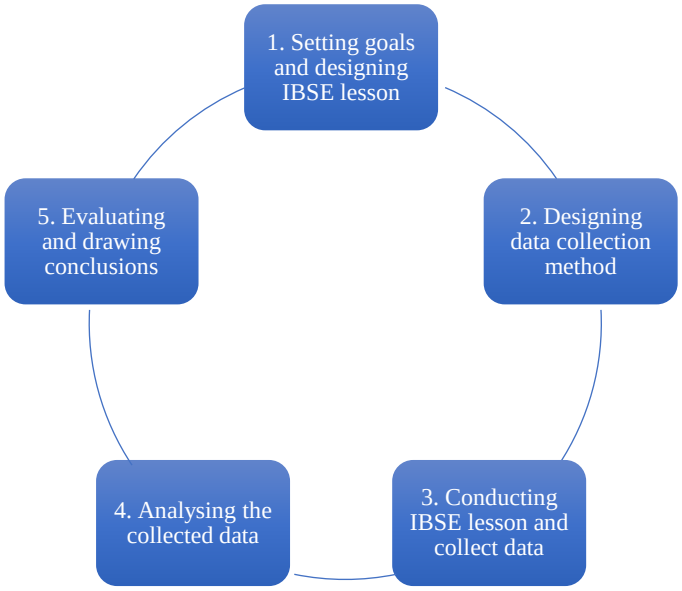
To ensure that teachers are equipped correctly to apply a new teaching theory in practice, this theory must be presented in such a manner that teachers are enabled to apply that knowledge directly in their practice and address the problems they expect when Appling theory into practice [31,32]. Therefore, the IBSE theory (about asking guiding questions and designing the 5E lesson) needs to be accompanied by good practices (video footage and descriptions illustrating intended teacher behavior) in a PDP; the key aspects of this design principle are how teachers apply what they learned from exploring the IBSE theory and the good practices with regard to 1) using hands-on and minds-on guiding questions and 2) designing IBSE lessons.

Design principle 2: Teachers develop their pedagogical skills by systematically collecting data and reflecting on that data

Teachers' pedagogical skills improve when they systematically assess their skills using data collected by themselves [33,34]. By assessing their pedagogical skills, themselves, they better understand the kind of approach that suits them best rather than acquiring this knowledge from theory [35]. Reflection on self-collected data enables teachers to determine decisions needed to further develop their pedagogical skills [36,37]. The pedagogical skills that teachers aim to improve in this PDP are linked to the phases of the 5E-model (Table 1). Two types of pedagogical skills are distinguished: pedagogical skills to support pupils' cognitive needs and pedagogical skills to support pupils' social needs [23,38].

The data feedback cycle (see Figure 1) is used to structure the teachers' process of assessing their pedagogical skills. The key aspect of this design principle is how the teachers apply the five steps of the data feedback cycle.

Figure 1: Data feedback cycle for developing IBSE teaching skills.



Note: Adapted from, Student teachers' use of data feedback for improving their teaching skills in science and technology in primary education, by Bom, P. L., Koopman, M., and Beijaard, D. (2019), European Journal of STEM Education, 4(1), p. 4.

Phase	Cognitive pedagogical skills:	Social pedagogical skills:
Engage	collecting materials connecting with pupils' everyday context eliciting students' prior knowledge (related to the lesson objectives) raising pupils' interest/motivation to learn	creating a social atmosphere in which pupils can express themselves freely
Explore	providing suitable and challenging materials presenting instructions clearly asking questions which evoke pupils' ideas and stimulate pupils to explore materials	encouraging pupils to bring questions forward stimulating self-confidence to do 'hands-on' activities
Explain	asking questions that lead to development of concepts and skills (drawing upon the Explore activities or data collected during the Explore activities) leading an interactive discussion driven by divergent and convergent questions	involving all pupils into the discussion
Elaborate	providing sufficient and appropriate materials to enable pupils to conduct their experiment/design enabling pupils to test their concepts by means of their experiments or designs coaching and stimulating small-group discussions about the experiment/design	making a deliberate group-distribution considering differences between pupils facilitating shared ownership within the small groups facilitating pupils' collaboration
Evaluation	determining beforehand which kind of presentation is most suitable enabling pupils to evaluate their own experiment/design	making pupils feel proud of their experiment/design

Table 1: Pedagogical skills per phases of the 5E instruction model.

Design principle 3: Teachers learn from each other's practice (in designing IBSE lessons as well as in inquiring their own practice) in collaborating peer groups

Exchanging ideas, opinions, and knowledge enhances the opportunity to develop new insights. The same applies to teachers who exchange teaching experiences within a peer group. Those teachers seem to develop their professional skills more rapidly than teachers who work individually [35]. Moreover, teachers appear to have more perseverance and are more motivated to develop their teaching skills when they repeatedly provide each other with feedback; individual ideas for solutions are sharpened and improved [33]. The greater the differences between the teachers' ideas within a peer group, the more ideas and teaching methods are exchanged, and the more learning activity within the peer group takes place [39]. The key aspects of this design principle are how teachers collaborate in a peer group regarding to: 1) designing IBSE lessons, 2) designing a data collection method in step 2 of the data feedback cycle, and 3) analyzing and interpreting the collected data in step 4 of the data feedback cycle (see Figure 1).

Design principle 4: The teacher educator enacts as a role model for teaching IBSE lessons and collecting, analyzing and interpreting data

Being a role model for teachers means more than just demonstrating the aimed pedagogical practice. Role models are supposed to also explain and discuss the motives that guide their actions. Teacher educators who enact as role models must

therefore explain the pedagogical backgrounds of their decisions and discuss them [40,41]. Teachers only fully understand their teacher educators' decisions when these are put into question and discusse [42]. In turn, this will encourage teachers to rethink and adapt their own teaching practice [43]. The key aspects of this design principle are how teachers experience the teacher educator's modelling of 1) teaching IBSE and 2) collecting and analyzing classroom data.

3. Method

In this study, an intervention by means of a data feedback program (this study's PDP) based on the four design principles was implemented. To examine how the participating PSTs and ISTs applied and experienced the key aspects of the programs' design principles, data were collected through logbooks kept by the participants and retrospective group interviews. Besides the researcher of this study, the participants also collected data but for the purpose of obtaining feedback regarding their pedagogical skills (part of the intervention). To distinguish these two modes of data collection, the tools used by the researcher were called instruments and those used by the participants data collection methods.

3.1 Context and participants

The study was carried out at four elementary schools in suburban areas in the Netherlands where S&T is taught occasionally, thought with the intention to implement S&T education on a structural basis. The participants volunteered; they were PSTs in the fourth and final year of their bachelor study (n=8) and ISTs (n=8). The PSTs had only internship teaching experience, the ISTs between 7 and 33 years. The participants collaborated in six different peer groups composed in consultation with the participants; two consisted of both PSTs and ISTs, two only of ISTs and two only of PSTs (see Table 2). In the groups with PTSs and ISTs, the ISTs were mentors of the PTSs. This was opted for, since this was the most common setting in which the professionalization of PSTs occurred and for mentors it was a logical step to reflect on their own teaching, in addition to mentoring their PSTs. Different group compositions were created to obtain insight into the range of similarities and differences in how ISTs and PSTs applied and experienced the key aspects of this study's design principles [44]. Initially each group consisted of three participants but since two participants dropped out, two peer groups were left with two participants. Each participant completed two data feedback cycles. At the start of the program, participants were informed that they could withdraw from the study at any time and that their anonymity was guaranteed. The first author of this study acted as researcher and educator; since the participants perceived him primarily as an educator, he clarified his role on every occasion that he acted as a researcher.

Participant	Student / years in service as a teacher	Peer group
Zoe	Student	A
Ada	Student	B
Tim	Student	B
Luke	Student	C
Luna	Student	C
Julia	Student	C
Rachel	Student	D
Ella	Student	D
Sarah	9	A
Eva	8	A
Nathali	11	B
Emily	33	E
Sophia	27	E
Alice	32	E
Anna	10	F
Yvi	7	F

Table 2: Overview of the participants' teaching experience and peer group composition.

3.2 Intervention

The data feedback program lasted three months and was arranged around two data feedback cycles; in total, the PDP consisted of eight elements: six group meetings of approximately two hours and two individual exercises. Table 3 provides an overview of all program elements and how the four design principles were integrated within the PDP.

Program element	**Activities participants**	**Involved design principles**
1. An introductory group meeting on teaching IBSE and designing 5E-model lessons	- Taking notice of and discussing the presented IBSE theory and the good practices - Participating in and discussing the teacher educator's example IBSE lesson (modelling)	1, 4
2. A group meeting on setting goals and designing IBSE lessons (first data feedback cycle step)	- Setting personal goals based on one or two pedagogical skills of Table 1 - Designing an IBSE lesson - Discussing personal goals and lesson design in the peer groups	1, 3

3. A group meeting centered on collecting and analyzing data (second data feedback cycle step)	- Taking notice of and discussing the teacher educator's explanation of how he collected and analyzed data (modelling) - Designing a data collection method - Discussing the data collection method in the peer groups	2, 3, 4
4. Teaching IBSE and collecting and analyzing data (the third data feedback cycle step)	- Conducting the designed IBSE lesson - Collecting data with the own data - collection method - Analyzing the collected data	2
5. A group meeting in which the collected data is presented and discussed (fourth data feedback cycle step)	- Presenting the collected data and how these were (tried to) analyze in the peer group - Discussing each other's data and analyses within the peer groups and (trying to) draw conclusions	2, 3
6. A group meeting centered on IBSE teaching and collecting data (first step - and start - of the second data feedback cycle)	- Revising the goals set in program element 2 - Designing a new IBSE lesson - Revising the data collection method designed in program component 3 - Discussing personal goals and the new lesson design in the peer groups	1, 2, 3
7. Similar to program element 4		
8. Similar to program element 5		

Table 3: The data feedback program and integrated design principles.

3.3 Instruments

Logbooks and focus group interviews were used to collect the data.

Logbooks

The participants reported on how they applied and experienced the key aspects of the four design principles while completing the data feedback cycles in an individual logbook. To gain a truthful picture, the participants were instructed to write down their actions and experiences as soon as possible after a data feedback step, at least within two days [45]. To support their logbook writing they received information, illustrated with examples, on how to write a logbook [46,47]. To obtain rich descriptions revealing not only how the participants acted but also how they experienced their actions, they were asked to write in a story-like manner [48]. During the data feedback steps the participants addressed the following questions in their logbooks:

Step 1: What pedagogical skill(s) do you want to improve? What IBSE lesson are you going to carry out? Did you collaborate in your peer group? If so, how? And how did you experience that? Did the educator support you in this step? If so, how? And how did you experience that?

Step 2: Which data collection methods are you going to utilize? What data do you intend to collect? Did you collaborate in your peer group? If so, how? And how did you experience that? Did the educator support you in this? If so, how? And how did you experience that?

Step 3: Which data were collected and what were your experiences during data collection? Did you collaborate in your peer group? If so, how? And how did you experience that?

Step 4: How did you analyze and interpret the collected data? Did you collaborate in your peer group? If so, how? And how did you experience that? Did the educator support you in this? If so, how? And how did you experience that?

Step 5: Did the reflection on the collected data change your view on your pedagogical skill(s), and if so, how? And how did you experience working with the used data collection methods?

Focus group interviews

After having finished their logbook for the second data feedback cycle, three focus group interviews were conducted. The first group consisted of three PSTs and three ISTs (group A and B), the second group of five PSTs (group C and D), and the fourth group of five ISTs (group E and F). The interviews aimed at gaining in-depth insight into how the participants performed and perceived completing the two data feedback cycles regarding each design principle [49]. During the interview, the four design principles were chronically discussed; it was examined how the participants applied and experienced the key aspects of the four design principles as mentioned at the end of each design principle in the theoretical section. The first author, who was the interviewer, kept the discussions within the boundaries of the subject and also encouraged the discussion without leading the participants to specific opinions [50]. Each interview lasted about 60 minutes and was audio-taped and transcribed verbatim.

3.4 Data analysis

The analysis of the logbook and interview data consisted of the following steps:

(1) The first author studied the logbooks and the transcribed focus group interviews in detail to familiarize himself with their content.

(2) Labels were assigned to text fragments varying from one to seven sentences. A fragment was characterized by the description of one particular activity or experience of a participant. For example, a list of questions a participant planned to ask while interviewing groups of pupils was labelled as questions group interview. For labelling the fragments, we followed an iterative process of going back and forth between theory derived from the description of the design principles and data reported by the teachers. This process, in which labels were (re)formulated and/or merged, resulted in labels doing justice to both. For example, the two preliminary formulated labels use questions from manual and draws up questions were merged into the label prepares guiding questions. This resulted in a set of 19 final labels as displayed in Table 4. ATLAS.ti 9 was used to label and organize all the fragments in line with the design principles. In total, 553 fragments were labelled.

(3) The labelled data were summarized and displayed in a matrix [47]. The rows represented the final labels, the columns the participants. The result was a description of how each participant applied and experienced the particular aspects of

design principles identified by the final labels. Representative quotes from the logbooks and the focus group interviews were added to the descriptions.

(4) To answer our research questions, an overarching and integrating matrix was developed consisting of three columns; the first column displayed the final labels, the second column summarized descriptions of the final labels based on a horizontal analysis of the first matrix, and the third column contained illustrative cases and quotes.

Design principle	Final label	Description of the label Fragments in which participants indicated…
1	Hands-on minds-on	to what extent they have applied hands-on minds-on questions as outlined in the IBSE theory, in their IBSE lessons.
	Good practices	to what extent they have used the good practices to design and conduct IBSE lessons.
	Designing IBSE lessons	how they have applied IBSE theory to design their lessons.
	Experiencing IBSE theory	how they experienced applying the IBSE theory to design and conduct 5E lessons.
	Experiencing differences between lessons	to what extend the first cycle's IBSE lesson was experienced differently form the second cycle's IBSE lesson.
2	Setting learning goal	which learning goals they formulated.
	Designing data collection method	which data collection method they chose/designed
	Collecting data	how they collected the data.
	Analyzing data	how they analyzed the collected data.
	Concluding	which conclusions they drew based on the collected data.
	Experiencing data feedback Differences between two cycles	how they experienced collecting and analyzing data. to what extent they collected and analyzed the data in the second cycle differently from the first cycle.
3	Collaborating in designing lessons	whether and how they collaborated in designing the IBSE lessons.
	Collaborating in designing data collection method	whether and how they collaborated in designing a data collection method.
	Collaborating in analyzing data	whether and how they collaborated in analyzing the collected data.
	Experiencing collaboration	how they experienced collaborating in conducting data feedback.
4	Modelling teaching IBSE	whether and how the teacher educators' modelling had (or had not) supported them in teaching IBSE lessons.
	Modelling collecting and analyzing data	whether and why the teacher educators' modelling had (or had not) supported them in collecting and analyzing data.
	Experiencing modelling	how they had experienced the teacher educators' modelling.

Table 4: The final labels and their description.

3.5 Reliability

To ensure reliability several measures were taken. First, each time after the first author had carried out one of the abovementioned data analysis steps, the followed procedure and results were verified by the co-authors and discussed with the researcher. Second, representative quotes from the primary data were used as illustrations of the findings. Third, an audit procure was conducted by an independent researcher to check the methodological choices, data analysis procedures, and interpretation of data. This audit was completed by following the steps presented by Akkerman et al. (2008) [51] and further refined by De Kleijn and Leeuwen (2018) [52]. The auditor took note of the primary data (logbooks and interview transcriptions) and verified the transparency and acceptability of 1) the labelling process and decisions taken therein (see examples in the second data analysis step), 2) the summaries and displays of the labels into a matrix, 3) the emergence of the overarching matrix, and 4) the description of the results based on the overarching matrix. The process of data analysis and interpretation was found to be satisfactory, yet the auditor advised to explain terms and abbreviations used in the underlying documents to enhance transparency. The audit report can be obtained from the first author on request.

4. Results

Design principle 1: Teachers learn to design and conduct IBSE activities by exploring the IBSE theory and experienced teachers' IBSE practice

1) Hands-on minds-on

All participants formulated hands-on and/or minds-on guiding questions for stimulating an ongoing dialogue in the classroom, although some participants prepared less questions than others. Only a few participants prepared hands-on and minds-on guiding questions for all the 5E phases of their IBSE lesson, the majority prepared such questions only for three or four phases.

These latter participants missed guiding questions for the second and/or fourth phase, in which the pupils carried out hands-on activities in small groups. An illustration of the hands-on and minds-on questions that were formulated was given by Alice, who prepared a 5E lesson on the theme 'air' and formulated hands-on questions such as 'how can you capture air?' (in the first phase) and 'how can you use air to lift something?' (in the second phase), and she prepared minds-on questions such as 'what is air?'

2) Good practices

The participants used the 'good practices' shown in the videos and books for two different purposes. Firstly, for finding ideas for their lesson design by modifying the 'good practices' to their own classroom situation. For example, because their pupils were younger or older than those in the good practice or because the materials in the good practice were not available or regarded less suitable than other materials. Eva used a large mirror to enhance her pupils' engagement in the classroom discussion on how mirrors function; this mirror was not used in the good practice she consulted. Secondly, some participants also used the good practices to obtain a true view of the required teacher behavior for IBSE teaching. For example, Ada expressed how a good practice affected her as follows: 'I saw how the teacher in the video encouraged her pupils' thinking by the funny way she asked them questions and I thought: I want to do it like that myself.'

3) Designing IBSE lessons

Nearly all participants designed IBSE lessons with five phases according to the instructions in the 5E-model. An illustration of such a 5E-lesson design was Julia's IBSE lesson on airplanes. In the first phase, she attempted to make two self-folded airplanes float in the air; one plane crashed, the other stayed afloat. She talked with her pupils about the difference between both planes. In the second stage, the pupils explored different shapes and materials to fold a plane that would float as far as possible. In the third stage, the pupils exchanged experiences and in the fourth stage they made their own plane. In the fifth and final phase, the planes were tested and discussed in the whole group.

4) Experiencing IBSE-theory

Except for one, all participants indicated they had experienced the IBSE theory and good practices as sufficiently supportive for designing and teaching their IBSE lessons. Most participants appreciated the combination of theory and good practices, although a few of them had a strong preference for one of these. Ella stated in the focus group interview: 'I'm not really into theory, the book with the good practices did help me to know how the IBSE lesson should be carried out', while Hannah indicated that the theory had supported her more. The description of the pupil and teacher activities during the different phases in the IBSE theory provided Hannah with sufficient tools to design her own IBSE lesson. Emily, however, was disappointed in the support offered by the IBSE theory, because she expected to receive already outlined lessons with clear instructions on how to carry them out.

5) Experiencing differences between lessons

All participating PSTs and four ISTs reported experiencing more tension and feeling less self-confident during the first IBSE lesson compared to the second; after the first lesson they had a better idea of how they could proceed the second lesson. Rachel expressed this as follows: IBSE-type lessons never were my favorite, I am someone who prefers to be in control, but in the second IBSE lesson I experienced I could loosen up much better and focus on the pupils' ideas and their enjoyment. This gave me a more satisfied feeling afterwards.

Yet four teachers experienced no substantial difference between the first and the second lesson. These teachers had taught IBSE lessons before albeit not by using the 5E-model.

Design principle 2: Teachers develop their pedagogical skills by systematically collecting data and reflecting on that data

1) Setting learning goals

All participants formulated learning goals that addressed their chosen pedagogical skills aimed at their pupils' learning in the first cycle. For example, Anna's learning goal was: 'By asking guiding questions, I want to stimulate my pupils to think and talk in small groups about their observations and thus enable them to discover new things'. In the second cycle, most participants kept the same learning goals as in the first cycle, but some PSTs reformulated them into more specific goals aimed at specific teacher behavior in the classroom. For example, Zoe's learning goal in the first cycle was to ask guiding questions to allow her pupils to adjust their concepts of floating or sinking; in the second cycle, she formulated a new learning goal only aimed at providing her pupils with sufficient thinking time after asking a guiding question allowing them to phrase what they really think. Her observation that she insufficiently enabled her pupils to phrase their thoughts in the first cycle prompted her to formulate a more specific learning goal in the second cycle.

2. Designing data collection method

The participants designed various data collection methods. Some PSTs designed forms for closed observations and prepared to collect video and audio data from their IBSE lesson. Zoe, for example, designed a closed observation form consisting of a list of statements such as: 'The teacher asks only one question at a time' and 'The teacher's question is unambiguous.' The other participants intended to conduct open observations. Julia, for example, aimed at improving her pedagogical skill 'to coach and stimulate small group discussions about the experiment/design' and prepared to make video and audio recordings which would enable her to assess her own behavior. In addition to observations, all participants prepared group interviews and formulated questions to address to their pupils after the IBSE lesson. In general, the questions formulated by the PSTs and ISTs who collaborated with them strongly focused on their learning goals. Luke, for example, aimed at improving the skill 'raising pupils' interest' in the first phase of his 5E lesson and formulated questions like: 'What did you think of the introduction? Do you think it was interesting?' and 'If so, what did you find interesting?' The ISTs in the homogeneous groups mostly formulated questions which were less specific and more focused on the IBSE lesson as a whole. For example, Sophia prepared questions focusing on her pupils' understanding of the subject matter such as: 'How can you make a sturdy tower?' However, Ivy prepared questions focused on her pupils' experiences during her IBSE lesson like: 'Have you tried out new things?' and 'How did you find that?'

3. Collecting data

All participants collected data by making video and audio recordings from their IBSE lessons and only audio recordings from the group interviews. To collect usable audio data from the

talks with their pupils during class work (phase 2 and 4), they used a clip-on microphone.

4. Analyzing data

The participants' data analysis methods aligned the nature of their collected data. Those who used a closed observation form, analyzed the video and audio recordings of their 5E-lesson by scoring and subsequently verifying in the video recordings whether and how they obtained scores related to their teacher behavior and arranged these data in a matrix. This was illustrated by Ada, who scored a high-level of pupil engagement during the group discussion and noted with this score in the matrix that she showed materials, asked the pupils open-ended questions, and showed interest in the pupils' responses. The participants who conducted open observations analyzed the relevant parts of the video and audio recordings in two different manners. The first manner was successively transcribing, labelling, and arranging the labelled data in a matrix showing how the pupils reacted to different teacher behaviors; this manner was applied by most PSTs. The second manner was applied by most of the ISTs and was more intuitive; the video recordings were observed and meanwhile taking notes of the perceived opportunities for improvement. Ana, however, concluded after the first cycle that this latter manner was insufficient and decided in the second cycle to transcribe some of her talks with pupils in order to learn how to improve her questioning skills.

5. Concluding

At the end of both data feedback cycles, almost all participants drew conclusions about the extent to which they had mastered the chosen pedagogical skills and, if they were not satisfied about their performance, how they thought to improve them. This is illustrated by Eva, who had observed in the video recording of her first lesson that she had hardly any content-related discussions with her pupils in the fourth phase of the 5E lesson. She concluded she was too afraid to hinder her pupils in following their own ideas by interfering and resolved this by using guiding questions precisely to stimulate her pupils in following their own ideas in her second IBSE lesson. After observing the second lesson, she was satisfied about how her guiding questions assisted the pupils. Most PSTs, however, decided at the end of the first cycle to make specific changes in their teaching behavior in their next IBSE lesson without explaining how those changes related to their original learning goal and their pupils' learning. Only at the end of the second cycle they drew such conclusions. For example, at the end of the first cycle Julia concluded that she had to spent more time with each of the small groups during the fourth 5E lesson phase, but she did not mention why and how to use that extra time. Only at the end of the second cycle she explained that she wanted to use the extra time with the small groups to embark on in-depth discussions with her pupils and that she needed to practice in asking proper guiding questions.

6. Experiencing data feedback

Most participants found data feedback a useful and straightforward manner to improve their pedagogical skills. Anna expressed this as follows: 'It was simple and targeted. You don't have to focus on everything, only a single focus on one particular skill'. Nevertheless, two ISTs objected to data feedback; one of them (Emily) stated that data feedback was too time-consuming for implementation in daily practice. In general, observation as data collection method was considered more useful than the interview method, because it provides direct insight into teaching behavior. Some PSTs, however, considered interviewing their pupils in the second cycle as useful, because their pupils then knew in advance what was going to be asked to them after the lesson and thus could respond better. Furthermore, Yvi mentioned that the interviews had aided her to have a good feeling about her IBSE lesson in retrospect, thanks to her pupils' overwhelmingly positive reactions.

7. Differences between two cycles

Most participants applied the same data collection methods in both cycles, although they adjusted their methods in the second cycle somewhat based on their experiences in the first cycle. An example of this was given by Ada who, in the group interviews in the first cycle, moved on to the next question when pupils said 'I forgot', but in the second cycle asked follow up questions to find out what they still knew.

Design principle 3: Teachers learn from each other's practice (in practicing IBSE activities as well as in examine their own practice) in collaborating peer groups

1. Collaborating in designing lessons

In the program meetings each participant's lesson design was presented and discussed within the peer groups. These discussions provided most participants with insights into how to improve their lesson design as illustrated by Ada when she described a discussion in which emerged that she better could change her introduction from a straightforward explanation into a narrative to enhance her pupils' engagement with the lesson topic. In addition to the formal meetings, participants also discussed their lesson designs at informal moments. Alice expressed this as follows: 'After school hours we often talk our IBSE lessons through.'

2. Collaborating in designing data collection method

Whether and how the participants collaborated in designing a data collection method varied. Most PSTs presented and discussed their data collection methods in the peer group and used peer feedback to adjust their data collection methods. The ISTs in the heterogenous groups, however, tended to use the PSTs' data collection methods and adapted these to their own context. Concerning the ISTs in the homogeneous groups, Yvi was the only one who discussed her data collection method and asked her peers for feedback.

3. Collaborating in analyzing data

Most participants analyzed the video recordings of their IBSE lessons together with one or two peer(s). They scored on the observation form (in case of closed observation) or labelled the transcriptions (in case of open observation) of themselves and their peer(s) independently. Afterwards, they compared the scores or labels to achieve a final score or label. This was illustrated by Ada who wrote: 'My mentor and I had different scores regarding some pupils' engagement. So, I discussed this with my mentor to decide which score most closely matched these pupils' engagement.' Some ISTs, however, did not use an observation form or labelling but watched each other's IBSE lessons together and stopped the video regularly to discuss why the teacher involved acted as such and how to do it better or differently.

4. Experiencing collaboration

All participants experienced collaboration in peer groups as pleasant and useful, particularly because their peers often had qualities or ideas that were different from their own. Exemplary in this regard are Rachel and Luna. Reflecting on collaboration, Rachel remarked: 'I appreciated Luna's feedback on my lesson design. I often thought things were complicated, but Luna came up with practical solutions.' Luna stated: 'I know how to design lessons but when it comes to analyzing data it's really helpful to have someone to spar with.' Initially the ISTs in the heterogenous groups were reluctant to allow the PSTs to assess their lessons, but afterwards these ISTs perceived this approach as instructive for themselves and beneficial for their relationship with the PSTs. Nathali remarked about this: 'It is actually good for your relationship with the PST. You really work together as colleagues, we all learn.' The ISTs in the homogenous groups experienced collaborating in designing lessons as beneficial in particular as this fitted within their school culture. The three ISTs who aided each other in analyzing the video recordings of their IBSE lessons experienced this as enriching, because it provided them with a better understanding of their own behavior. Anna expressed her experiences as follows: 'While I watched the video of the lesson with my colleague, the messiness no longer bothered me, I started focusing on how to improve my pupils' learning.'

Design principle 4: The teacher educator as a role model for teaching IBSE activities and conducting research

1. Modelling teaching IBSE

The teacher educator's modelling of the IBSE lesson assisted the participants in different manners. The PSTs reported that this allowed them a better understanding of the 5E lessons' structure. For example, Luke stated: 'I didn't know the 5E-model very much, so the modelling really helped me to structure my own lessons well.' Most ISTs indicated to have learned particularly from the teacher educator's application of guiding questions, expressed by Sophia as follows: 'You (the teacher educator) did not prescribe anything (in the model 5E lesson). You kept asking guiding questions. That made me ponder.'

2. Modelling collecting and analyzing data

The teacher educator's modelling of collecting and analyzing data reflecting his own practice was not followed by all participants. Except for Anna, who transcribed the dialogues with her pupils in the IBSE lesson. The ISTs in the homogeneous groups collected and analyzed data according to their own insights rather than as shown in the modelling. In contrast, the PSTs and the ISTs collaborating with them applied the methods of data collection and data analysis more or less as shown in the modelling (for example, using a matrix to arrange data). However, they also used the available literature about data analysis as provided during their study, so it was difficult to establish to what extent the modelling had assisted them in this.

3. Experiencing modelling

As explained above, most participants experienced the teacher educators' modelling as beneficial. Anna reported on how she experienced the modelling as follows: 'It made me feel good that the teacher educator was also present as a learning individual and explained from his own perspective how he does things and what his dilemmas are. That gave me confidence.' Two participants experienced modelling of the IBSE lesson as not being helpful. Since the teacher educator had conducted a model lesson with an engineering topic aimed at pupils aged between 9 - 11 years, Emily and Ada had difficulty in seeing the connection between the model lesson and their own lessons. Emily had planned to conduct lessons with science topics and Ada's pupils were young (5 years). Both participants indicated that they preferred instructions on how to act in each step of the 5E-model instead of the modelling.

5. Discussion

5.1 Discussion of the main findings

The findings regarding how teachers apply the key aspects of the four design principles underlying the data feedback program indicate that most teachers applied the key aspects in accordance with the literature. For example, almost all teachers designed two 5E model lessons and formulated hands-on and minds-on guiding questions consistent with the provided IBSE theory and good practices. Apparently, the combination of directly applicable IBSE theory and the good practices supported teachers sufficiently in applying the theory in practice. Good practices generally seem very relevant for convincing teachers to embrace new educational theory, because of their potential to successfully bridge between theory and practice [31]. Our findings also show that most teachers formulated clear personal learning goals, collected appropriate data and managed to analyze these data so that they were able to draw conclusions on how to improve their IBSE teaching. It can be concluded that employing the design principles has resulted in a data feedback program in which teachers were truly supported in developing their pedagogical skills and overcoming difficulties they encounter in teaching S&T.

The findings regarding how teachers experienced applying the key aspects of the four design principles show that most teachers appreciated applying the key aspects, because these supported them to improve their IBSE teaching and provided them with clear and targeted directions. The teachers who did not appreciate applying one or more of the key aspects, indicated not to see the relevance of the key aspect at issue. In such cases, the proposed key aspect may have conflicted with what teachers' themselves considered important for their practice [32].

Some findings will be further addressed here. First, relatively many teachers failed asking hands-on and minds-on questions when their pupils conducted hands-on activities in small groups (second and fourth 5E-model phase). This finding is in line with another study illustrating that even after intensive training, teachers struggle in using guiding questions to stimulate their pupils' thinking in group activities [53]. It is likely that organizing group work occupies the teachers during group activities by pupils [31]. On the other hand, it is also known that elementary school teachers often lack S&T knowledge [26]; this might have limited them to ask guiding questions that prompt their pupils to reflect.

Second, it was striking how differently ISTs and PSTs in the homogeneous groups analyzed their data. PSTs often used analysis methods as transcribing, labelling, and placing the labelled data in a matrix. Although the ISTs in the homogeneous groups were expected to perform a similar approach, they only analyzed their data on a general level. This difference can be attributed to experienced teachers who, in general, tend to avoid new methods unless they are convinced of their added value for their own teaching [54]. Learning analyzing classroom data adequately demands an investment from the teachers, which

they only tend to undertake if they believe that this helps them to improve their practice. For example, IST Anna employed an analysis method (transcribing her talks) after being convinced of its merit. PSTs, on the other hand, generally are open to new learning experiences because they are aware they still have a lot to learn [13].

Third, Some PSTs, like Zoe, shifted their goals in the second data feedback cycle from pupil-centered (in the first cycle) to goals aiming at specific behavior of themselves and seemed to have lost their view on their pupils' learning in the process. Most likely, this was due to the fact that the teachers had experience with IBSE or at least with parts of it such as carrying out class discussions, while the PSTs had much less of this kind of experience and still had to acquire some basic skills. Nevertheless, the finding that all PSTs formulated pupil-centered goals and tailored their teaching accordingly in the first data feedback cycle illustrates that also inexperienced teachers are capable in doing this, but that this needs continuous support.

Fourth and finally, the participating teachers complemented each other and (to some extent) sharpened each other's thinking due to the differences between the group members, like Ella and Ana as well as Luna and Rachel did [55,39]. Remarkedly in the groups with fewer differences between the peers (the IST-only groups), the group members collaborated intensively in designing lessons but much less in analyzing data, while the ISTs in the heterogeneous groups were far more willing to analyze the data together with the PSTs and even appreciated what they learned from that. This finding argues in favor of collaboration between ISTs and PSTs with benefits for both. Several studies provide evidence that PSTs benefit from such collaboration, but studies on behalf of the benefits for ISTs are to our knowledge lacking [56,57].

5.2 Implications for practice

The results of this study confirm the usefulness of the four principles for designing a data feedback program to support teachers in their S&T-teaching. The study revealed several points of attention. First, to prompt experienced teachers to analyze their classroom data more deeply they need to be convinced of its benefits. Anna's learning experiences, for example, may be used as case materials for this purpose [48]. Second, it is necessary to assist teachers to remain focused on their pupils' learning throughout the program, for example, by continuously stimulating reflection on their goals. Third, most teachers found it difficult to continue the ongoing dialogue on S&T topics when their pupils conducted hands-on activities in small groups. Even though this issue is persistent, it is likely that illustrative good practices might provide teachers with clues on how to overcome this difficulty [55]. In addition, it is advisable to professionalize both PSTs and ISTs in asking guiding questions that prompt their pupils to reflect on their hands-on findings; even though this is a challenge considering this kind of professionalization is not preferred by most PSTs and ISTs [15]. Fourth and finally, our findings showed unintentional discrepancies between the teacher educator's modelling and teachers' practice. Teacher educators ought to remain alert to teachers not recognizing their practice in their modelling and allow them to discuss their perception [42].

5.3 Limitations and suggestions for further research

Only eight PSTs and eight ISTs participated in this study. They also collaborated in differently constituted peer groups. It is therefore not possible to generalize the findings. However, because of the variation in participants and group composition, the collected data reflected a broad range of similarities and differences in how ISTs and PSTs applied and experienced the four design principles. Additionally, the first author of this study acted as program developer, researcher and educator. Although necessary reliability measures were built in, this combination of roles might not be unbiased.

Some key aspects of the design principles were not applied and/or experienced as intended by all teachers; for example, with regard to preparing hands-on and minds-on questions to be used when their pupils conducted hands-on activities and analyzing the data adequately. This DBR showed the applicability and functionality of the data feedback program's design principles in practice. Future DBR could focus on the most appropriate implementation strategies and conditions for using these design principles in elementary school teams, in teacher education institutes or in hybrid spaces in which PST and IST collaborate [19,20]. We also recommend DBRs that further explore how ISTs and PSTs can sharpen each other in Appling data feedback when implementing S&T (or STEM) in elementary schools.

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Declaration conflict of interest

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Conformations

All above mentioned authors have approved the manuscript for submission. The content of the manuscript has not been published elsewhere.

Appendix A

Design principle	Type of support	The data feedback cycles as conducted in the pilot study	Additions and amendments in this study's data feedback program
1. teachers learn to design and conduct IBSE lessons by exploring the IBSE theory and experienced teachers' IBSE practice	Support in gaining in-depth knowledge about IBSE.	Explanation of the IBSE theory, the 5E model and the corresponding pedagogical skills completed with practical examples that provide a general idea of how an IBSE lesson looks like.	Good practices (video footage* and descriptions of IBSE lessons**) that showcase specific pedagogical skills related to managing a 5E lesson and/or stimulating the ongoing dialogue, were provided and discussed in the peer groups.

2. teachers develop their pedagogical skills by systematically collecting data and reflecting on that data	Support in formulating clear personal goals, collecting and analyzing data, and in reflection on the analyzed data.	After being instructed on how the data feedback cycle operates, the participants completed this cycle twice. Textbooks with instructions on how to collect and analyze data were provided and explained.	1) the PSTs of this study are not third year but fourth year PSTs who have acquired more research skills. 2) to aid teachers in formulating personal learning goals regarding their chosen pedagogical skills they answered the following questions: 1) what do I want my pupils to say concerning the skills, after the lesson? and 2) what do I want a colleague, who observed the IBSE lesson, to say concerning my chosen skills? 3. the participants have the possibility of personal guidance from the teacher educator in designing a data collection and in analyzing and interpretating the collected data.
3. teachers learn from each other's practice (in designing IBSE lessons as well as in inquiring their own practice) in collaborating peer groups	Stimulating participants to support each other.	The participants provide feedback in peer groups on each other's learning goals, data collection methods and on the analysis and interpretation of the collected data.	To facilitate more targeted peer feedback, a list of questions to be asked to each other is drawn up for both group meetings (steps 2 and 4 of the data feedback cycle), with questions for the meeting in step 2 as: do you expect your observation method yields a clear answer to your research question (why or why not) and are the interview questions comprehensible to pupils; and for step 4 as: in what way would you analyze your data differently/in more in-depth and do the conclusions allow you to know how to improve your pedagogical skills.
4. The teacher educator enacts as a role model for teaching IBSE and collecting, analyzing and interpreting data	Support in reflecting on and enhancing IBSE teaching and data feedback knowledge	no modelling	The teacher educator conducts exemplary: 1) an 5E-lesson and applies the corresponding pedagogical skills and 2) interviews and observations and analyses the data to examine whether the participants have experienced the lessons as intended, and discusses his exemplary performances with the participants.
*** e.g.** videoclips of Centrum voor Talentenkracht Nijmegen (n.d.) [58] **** e.g.** Van Den Berg et al. (2013) [59]			

Table 5: The four design principles and their deployment in the data feedback program.

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