Scientific understanding of students in the picture

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Appendix A

Teacher	Lesson	Condition	Dispersion	Attractor cells			Expected change
				Cells	Total duration	Number of events	
1	1	1	0,892	11	70	9	Yes, change from *non-optimal* to *optimal* attractor Temporal instability: Yes Dispersion: lesson 4 NAS: 4 & 5
	2		0,9	21	93	17	
	3		0,856	43	77	14	
	4		0,833*	NAS			
	5		0,95	NAS			
	6		0,921	51; 52	36; 58	6; 10	
	7		0,918	43	86	15	
	8		0,941	33; 53	67; 79	13; 10	
2	1	1	0,932	NAS			Partly, no change from *non-optimal* to *optimal* attractor. But there is a temporal change in preferred states Temporal instability: Yes Dispersion: lesson 4 & 8 NAS: 4, 5 & 6
	2		0,929	NAS			
	3		0,902	11	77	12	
	4		0,806	NAS			
	5		0,951	NAS			
	6		0,93	NAS			
	7		0,925	21; 23	88; 94	14; 11	
	8		0,761**	11	112	14	
3	1	1	0,946	NAS			Partly, no change from *non-optimal* to *optimal* attractor. But there is a temporal change in preferred states Temporal instability: No Dispersion: constant non-significant variability between lessons NAS: 1, 2, 3, 5, 6, 7, 8
	2		0,878	NAS			
	3		0,933	NAS			
	4		0,869	53	95	12	
	5		0,893	NAS			
	6		0,865	NAS			
	7		0,938	NAS			
	8		0,955	NAS			
4	1	1	0,906	11; 21	87; 70	18; 13	Partly, change from *non-optimal* to 'sub-optimal' attractor and temporal change in preferred state Temporal instability: Yes Dispersion: lesson 3 NAS: 4 & 5
	2		0,951	NAS			
	3		0,875*	21	118	17	
	4		0,933	NAS			
	5		0,941	NAS			
	6		0,92	21	87	14	
	7		0,92	21; 51	66; 67	15;14	
	8		0,926	11; 21	65; 73	11; 15	
5	1	1	0,949	NAS			Partly, change from *non-optimal* to *optimal* attractor – not anymore at post-measure. Change seem to start late Temporal instability: Yes Dispersion: lesson 8 NAS: 7 & 8
	2		0,918	11	95	16	
	3		0,922	21; 31	62; 73	13; 20	
	4		0,945	21	68	12	
	5		0,926	31; 33	63; 73	15; 9	
	6		0,887	41; 43; 51	36; 48; 34	6; 7; 5	
	7		0,954	NAS			
	8		0,877*	NAS			
6	1	1	0,767**	NAS			Yes, change from *non-optimal* to *optimal* attractor Temporal instability: Yes Dispersion: lesson 1 NAS: 1 & 7
	2		0,926	11	65	14	
	3		0,93	11	76	17	
	4		0,898	11; 21	74; 74	15; 16	
	5		0,923	21	69	10	
	6		0,955	53	77	15	
	7		0,952	NAS			
	8		0,894	53	145	24	
7	1	1	0,896	11; 31	78; 89	19; 13	Yes, change from *non-optimal* to *optimal* attractor Temporal instability: Partly Dispersion: Constant variability between lessons – gradual increase NAS: 3, 5, 6, & 7
	2		0,869	11	82	19	
	3		0,859	NAS			
	4		0,891	51; 53	66; 117	16; 21	
	5		0,909	NAS			
	6		0,906	NAS			
	7		0,938	NAS			
	8		0,932	53	87	16	

8	2	1	0,907	11	107	20	Partly, change from *non-optimal* to ‘sub-optimal’ attractor. Change seem to start late Temporal instability: Partly Dispersion: Constant variability between lessons NAS: 8
	3		0,925	42; 11	97; 93	10; 15	
	4		0,895	31	95	22	
	5		0,917	11; 41	71; 63	11; 13	
	6		0,897	41	76	15	
	7		0,943	51	71	13	
	8		0,955	NAS			
9	2	1	0,881	NAS			No, no change from *non-optimal* to *optimal* attractor Temporal instability: Yes Dispersion: lesson 4 NAS: 2, 3, 4, & 5
	3		0.898	NAS			
	4		0.757*	NAS			
	5		0.935	NAS			
	6		0.841	11	80	13	
	7		0,887	11	78	9	
	8		0,9	11	64	12	
11	1	2	0,961	NAS			Yes, No change in attractors
	2		0,907	21; 51	68; 62	11; 5	
	3		0,941	21	57	9	
12	1	2	0,857	21	63	12	Yes, No change in attractors
	3		0,876	NAS			
	4		0,867	NAS			
13	1	2	0,772	11; 21	97; 131	16; 24	Yes, No change in attractors
	2		0,675	11; 21	85; 150	17; 28	
	3		0,688	11; 21	187; 139	27; 22	
	4		0,795	11; 21	79; 84	16; 13	
14	1	2	0,926	31	72	17	Partly, change from *non-optimal* to ‘sub-optimal’ attractor
	2		0,891	11; 21; 31;	104;83;93;63	16;15;16; 14	
	3		0,903	41	71	14	
	4		0,955	11	84;66	17;10	
				11; 43			
15	1	2	0,812	11; 21	117; 86	14;14	Yes, No change in attractors
	2		0,867	21; 31	123; 62	19;17	
	3		0,801	11; 21	73; 81	11;17	
	4		0,913	11; 31	65; 57	12;13	
16	1	2	0,857	11	75	7	Yes, No change in attractors
	2		0,84	11	99	18	
	3		0,91	NAS			
17	1	2	0,89	NAS			Yes, No attractors
	2		0,773	NAS			
	3		0,884	NAS			
	4		0,945	NAS			
18	1	2	0,883	NAS			Yes, No change in attractors
	2		0,751	11; 21	90; 95	15;25	
	3		0,793	NAS			
	4		0,707	11; 21	105; 69	18;18	
19	1	2	0,922	31	68	15	Yes, No change in attractors
	2		0,819	11; 21	90; 115	15;15	
	3		0,897	31	66	16	
	4		0,912	21	67	13	
20	1	2	0,915	11	73	12	Partly, change from *non-optimal* to ‘sub-optimal’ attractor
	2		0,907	11; 21	72; 92	15;20	
	3		0,915	11; 21; 31	101; 73; 75	19;13;17	
	4		0,953	51	74	7	
21	1	2	0,872	11	72	10	Yes, No change in attractors
	2		0,821	11;21	91; 116	15;18	
	3		0,944	21	67	14	
	4		0,673	NAS			

Condition: 1 = intervention; 2 = control. Dispersion: range 0 to 1. Per lesson *dispersion* and *attractors* are shown. *Attractors* are accompanied by the total duration of that state and the number of events (recurrence to the state). The notation of the attractor cell is teacher/student; 51 = fifth cell on x-axis/first on y-axis = follow up/non-complex. NAS = No Attractor Specified. Expected change (last column) for intervention condition was: from *non-optimal* (11/21/31) to *optimal* (43/53/42/52); for control condition remain in *non-optimal*. * $p < 0.05$; ** $p < 0.1$.

Appendix B

Coding of verbal utterances

This appendix shows shortened versions of the coding schemes.

General coding guidelines

The verbal expressions of teachers and students were coded in three steps using coding software (Mediacoder; Bos & Steenbeek, 2007). The coding procedure consisted of the following steps:

1. Fragments of lessons were selected.
2. The exact time points of the utterances of the teacher and students were determined. Silence, classical time, and walking towards another group of students (implying a new interaction) were coded as well.
3. The utterances were classified using different coding schemes. The coding schemes differed depending on the research questions.

Selection of fragments

Ten minutes of the central part of the lessons were coded, because in this part a relatively larger amount of rich, interactive interaction was present. The central section was defined as the part of the lesson where students were working in small groups and the teacher walked around to see whether they needed assistance. During the central part of the lesson students and teacher went through several steps of the empirical cycle. To ensure that all steps could, in principle, be accounted for during the ten minutes, four segments were selected. A three-minute segment from the beginning, a three-minute segment from the end, and two two-minute segments from the middle. To ensure that the starting point of the central section would be the same for all lessons, the moment of the first substantive verbal expression was used. The two two-minute segments were chosen based on the fragments which captured as much interaction as possible – often these fragments could be selected based on the fragments listed during the recording of the lessons. These ten minutes were considered to represent the interaction during the central part of the lesson well.

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Coding scheme 1: Teachers' degree of stimulation[11]

Based on Meindertsma and colleagues (2014) and Oliveira (2010)

All substantive verbal teacher reactions are coded. Non-substantive utterances are 'Mind your language', 'Please sit down on your seat', and 'Five more minutes', etc. (code 9).

<u>Code within the stimulation scale</u>; only teacher reactions were coded. Stimulation is defined here as the extent to which teachers use verbal actions to elicit display of higher levels of students' scientific understanding. The scale ranged from 'giving instructions', 'providing information', 'asking a knowledge-based or closed question', 'posing encouragements', to 'posing a stimulating task-related follow-up or thought-provoking open question'. 'Giving an instruction' is considered as least stimulating because it is considered to be associated with the smallest possible chance of evoking a high level of reasoning. 'Posing a task-related follow-up' is considered to be most thought-provoking.

Teacher Stimulation, from non-stimulating to more stimulating.

0 – Instruction

The teacher assigns a task; either the imperative is used or the teacher embeds her instruction in an explanation. What defines an instruction, however, is that the *only* option given to the student is doing what the teacher has said.

Examples: *'Start working on task one'*
'Decide on your framework first'

1 – Giving information

The teacher tells the student what something is, explains how something works, paraphrases what the student is doing/saying (not literally), or suggests how the student might be able to go about a set task (the student has a choice in whether or not to follow the teacher's suggestion).

Examples: *'The universe is expanding'*
'It's because of air pressure'

2 – Closed question

The teacher asks a question that is focused on the end-result. There is a limited amount of answer-possibilities, sometimes only '*yes*' or '*no*', but also knowledge questions. If the teacher asks a student to confirm something, for example by literally repeating the question posed by a student, a '2' is also coded.

Examples: *'What is it called when this happens?'*
'What is this going to look like?'

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[11] Note that the 'openness' codebook and 'stimulation' codebook comprise highly similar codes. However, the 'stimulation' codebook specifically focuses on substantive utterances and on reactions. In addition, the ordinal scale aims to capture the extent to which the teacher aims to explicitly deepen students understanding.

Questions that are used as ‘check-questions’ also belong to this category.

Example: *‘So, you say your boat will float because of its size?’*

3 – Encouragement

The teacher gives a so-called ‘listening response’ that stimulates or invites the student to refine their reasoning. It’s not about the cognitive level of the student’s reasoning, but about the teacher giving the student enough space and encouragement to allow the student to reveal their thought process. It can be a simple utterance such as ‘*Yes*?’, ‘*Okay’* or *‘Hmmm’* or a literal repetition of a student’s utterance, as long as it is attentive, stimulates the interaction, and the interaction does not suddenly come to a halt. It can also be a compliment or affirmation that invites the student to continue their story.

4 – Follow-up

The teacher aims to deepen students understanding. This can be done by asking a question that is focused on the process. There are multiple answer-possibilities and often not one correct answer.

Examples: *‘How could you approach this?’*
‘Why do you think that is?’

Another possibility is that the teacher poses his or her own surprise or confusion or uses a comparison. The student is actively stimulated to deepen their understanding.

Example: *‘That is weird, I thought the paper would decent’*
‘When I let air out of a balloon, the balloon becomes smaller. Now you tell me, that if I put air in a marshmallow it will grow. I don’t get it.’

Note: the questions belonging to the empirical cycle are usually student centred as well as questions that elicit higher order thinking skills (i.e. explaining the thinking process):

Hypothesize

‘What do you think will happen when oil and water are poured together?’
Explain thinking process *‘Why?’*

Research design

‘*How can you study this?’*
Explain thinking process *‘Why would that be effective?’*
‘What do you need to explore this?’
Explain thinking process *‘Why?’*

Observation

‘*What do you see?’*
‘*What happened with …?’*

Drawing conclusions

‘*What can be the reason?’*
‘You expected something else, how would you explain that?’

Coding scheme 2: Students’ scientific understanding

Based on Skill Theory (Fischer & Bidell, 2006; Meindertsma, Van Dijk, Steenbeek & Van Geert, 2012; Rappolt-Schlichtmann, Tenenbaum, Koepke, & Fischer, 2007; Van der Steen, Steenbeek, Van Dijk, & Van Geert, 2014)

All verbal student expressions are coded. First all utterances are coded as *complex* or *non-complex* utterances. *Non-complex* utterances are utterances that could not be scored using Skill Theory.

0 – Other / non-substantive utterances

Examples: *‘Juf (*Dutch for teacher*), when can we play outside?’*
‘Look, my mom is walking outside’

1 – Task-related utterances (not scalable on complexity)

Examples: Reading the task out loud.
‘We need to put the paper on top of the books’

Complex utterances are those utterances that could be scored using Skill Theory. However, as we were solely interested in the reasoning processes of students, we focused on student’s explanations and predictions. Observations were not scaled on complexity, but were coded as observations. The complexity levels of student answers ranged from sensorimotor system (Level 3) to single abstractions (Level 7).

2 – Observations (sensorimotor actions or sensorimotor systems)
A student states single characteristics of a task that he or she observes.

Example: *‘It [the paper] is* white’

3 – Sensorimotor system
Simple, i.e. observable causal relations, causal mechanisms were stated.

Example: *‘The paper collapses* because I blow’

4 – Single representations
One part of the explaining mechanism was mentioned, or a not directly observable relation or object was mentioned as a mechanism. Simple predictions.

Example: ‘I think *the paper will ascend’*

5 – Representational mappings
Two or more parts of the explaining mechanism were coupled. Predictions in terms of a relation between two single representations. A superlative in one representation is used (but not yet linked to the change in another representation)

Example: *‘Because I blow, there is* more space *and then the* paper can go down.*’*

6 – Representational systems

A combination of all relevant parts of the explaining mechanism is mentioned or two representational mappings are coupled, i.e. a change in one representation causes a change in another.

Example: *‘Because I blow hard*er*, the paper can drop low*er*.’*

7 – Single abstraction

A general (immaterial) concept that goes beyond (representations of) the material is mentioned as an explaining mechanism.

Example: *‘Because the balance is gone… the air beneath the paper is pushed away [when I blow]… so… the* air pressure *drops down, but the pressure above the paper remains the same and thus pushes the paper down’*

Coding scheme 3: Teachers' openness[12]

Based on Meindertsma and colleagues (2014) and Oliveira (2010)

All verbal teacher expressions are coded. Only if a teacher expression does not fit anywhere an 'O' for 'other' may be coded. After having coded a teacher expression, categorise the statement by putting either an 's' (substantive) or 'n' (non-substantive) in the comment section. A substantive expression is considered to be a remark or question that relates to the content of the set task; a non-substantive expression is either procedural or unrelated to the set task. Both types can provide an indication of the level of teacher openness. What is being looked at is the degree of freedom that is given to the student; more teacher openness means an increase in the amount of potential responses a student can give.

Teacher Openness, from closed to more open:

0 – Stop

The teacher gives no opening wherein a student can respond by continuing to talk, talking over students, walking away or turning her back to students with whom she was involved in interaction (the interaction stops). Complimentary expressions such as '*Okay'*, '*Good'* or '*Well done'* are given stop-codes when the teacher uses these expressions to end the interaction.

When the stop-code is given because the teacher walks away or turns her back to student(s) with whom she was interacting, a 'W' (Walking away) is added to the comment section.

1 – Instruction

The teacher assigns a task; either the imperative is used or the teacher embeds her instruction in an explanation. What defines an instruction, however, is that the *only* option given to the student is doing what the teacher has said.

Examples: '*Start working on task one'*
'Decide on your framework first' are substantive examples
'*Mind your language'*
'Don't talk out of turn' are non-substantive examples.

'Gosh, that sounds very interesting, do tell…' would be coded with a '5' (Encouragement) despite the use of the imperative, as 'do tell' stimulates the student to elaborate, and transfers the initiative to the student. The initiative remains with the teacher when an instruction is given.

2 – Giving information

The teacher tells the student what something is, explains how something works, paraphrases what the student is doing/saying, or suggests how the student might be able to go about a set task (the student has a choice in whether or not to follow the teacher's suggestion). Teacher affirmations are sometimes coded as '2'; the prerequisite for this to happen is that

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[12] Note that the 'openness' codebook and 'stimulation' codebook comprise highly similar codes. However, the 'openness' codebook focuses on all utterances, i.e. non-substantive and substantive utterances, and initiations and reactions. In addition, the ordinal scale aims to capture the extent to which the teacher provides degrees of freedom for students to continue to reason scientifically.

the affirmation is not stimulating or inviting, but at the same time does not stop the interaction. For example; a student may ask whether they have done the task correctly, and the teacher may say '*yes'* or '*yes, well done'* to affirm that they have. The teacher is providing the student with the information that they have understood the task.

Examples: *'The universe is expanding'*
'It's because of air pressure' are substantive examples
'You can get the materials from my desk'
'Five more minutes' are non-substantive examples.

3 – Teacher-centred question

The teacher asks a question that is focused on the end-result. There is a limited amount of answer-possibilities, sometimes only '*yes*' or '*no'*. If the teacher asks a student to confirm something, for example by literally repeating the question posed by a student, a '3' is also coded.

Examples: '*What is it called when this happens?'*
'What is this going to look like?' are substantive examples.
'If you don't try you'll never find out, won't you?'
'*What did you say?'* are non-substantive examples.

4 – Student-centred question

The teacher asks a question that is focused on the process. There are multiple answer-possibilities. If a student comes up to the teacher to ask a question and the teacher responds by saying '*Yes?*' or *'Yes, … (*name of student*)?*' in a questioning manner, a '4' is also coded. This because it is considered to be equivalent to '*What is it*?' or '*What do you want to tell me/ask me?*' The degrees of freedom that are being given to the student are high, but the student is not yet being encouraged to elaborate on something they've started to ask or tell.

Examples: *'How could you approach this?'*
'Why do you think that is?' are substantive examples.
'Why don't you ask your classmates for help?'
'What do you think you'll achieve by behaving this way?' are non-substantive.

5 – Encouragement

The teacher gives a so-called 'listening response' that stimulates or invites the student to elaborate on their story or refine their reasoning. It's not about the cognitive level of the student's reasoning, but about the teacher giving the student enough space and encouragement to allow the student to reveal their thought process. It can be a simple utterance such as '*Yes*?', '*Okay'* or '*And after that*?', as long as it is attentive, stimulates the interaction, and the interaction does not suddenly come to a halt. It can also be a compliment or affirmation that invites the student to continue their story.

O – Other

The teacher expression fits none of the categories.

Coding scheme 4: Students' engagement[13]

Based on the Leuven Involvement Scale (Laevers, 2005) and the Specific Affect (SPAFF) Coding System (Coan & Gottman, 2007)

All verbal student expressions are coded. While coding verbal student expressions, nonverbal aspects are taken into account: the codes are based on the student's **intonation**, **facial expression**, **posture**, muscle tension, physical activity, and gaze direction as well as on the verbal statement itself.

It may occur that a student expression is from a different student than the student(s) with whom the teacher was previously involved in interaction (e.g. a student from a different table asks a question, or a student from the same table who only occasionally contributes suddenly says something). When this happens, a 'D' (different) is added as a comment.

A nonverbal engagement score is coded immediately after a nonverbal stop-code has been given to the teacher (i.e. a 'W' has been added to the comment section of the stop-code to indicate that the teacher walked away). This nonverbal engagement score is given to the student or students the teacher was interacting with, and is based mainly on facial expression and posture. Add 'nv' to the comment section to indicate that the engagement score is nonverbal, and make it 'nv G' if the teacher was interacting with a group.

Student Engagement, from disengaged to engaged

0 – Active away behaviour

The student purposely occupies himself with something other than the set task in order to avoid contact with the teacher, the task or both. Active away behaviour usually occurs in a context wherein something has just happened with the teacher (e.g. a conflict), or wherein the task has just failed and the student has gotten angry. The student can also be asking the teacher for social-emotional support, and use this to distract from the set task. Either way; the student is unwilling to do what is required of them.

Signs:	*affectively charged context, frowning, concentrated on non-task related behaviour, muscle tension.*
Examples:	a student starts a conversation with his teacher about how he cannot draw (and is henceforth "incapable" of starting or completing the task). a student argues that a task is stupid and is purposefully careless with the material. A student shows 'clowning'-behaviour and feels the need to make inappropriate jokes or comments that divert from the task.

1 – Boredom

The student is not at all or hardly focused on the task, but this does not occur in an affectively charged context as it does with active away behaviour.

It can also be referred to as 'passive away behaviour'. A certain amount of disinterest is involved. Although it is important that the student shows (almost) no task-focus, it is just as important that the student is not actively resisting the task, either. When the student does occupy themselves with the task, this is exceptionally short (e.g. the student reads part of the instruction for an assignment out loud but proceeds to get distracted by what's happening around him).

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[13] This codebook is developed as part of Nindy Brouwers' masterthesis.

Signs: *dreamy behaviour (e.g. staring out of the window), task-postponing behaviour (e.g. taking more time than necessary to collect the right supplies), sighing, sitting sprawled in their chair, and high distractibility.*

2 – Resignation

The student shows more task-focus than when in a state of boredom, but mostly seems to have resigned to the task. Fulfilling the task proceeds slowly and appears onerous.

The student is capable of reading instructions out-loud and of not or hardly getting distracted while doing so, but it proceeds unnecessarily slowly and is done with a closed facial expression and posture. The student seems reluctant to work and reluctant to respond to the teacher's questions.

Signs: *low energy-level, yawning, pausing while speaking (i.e. thinking out loud or asking a question happens slowly, speech appears strenuous and is interspersed with unnecessary breaks, "ehm" is often used as a filler-word), slight negative affect made apparent by downcast eyes and sagging shoulders.*

3 – Frustration

The student is reasonably focused on the set task, but visibly struggles with it and gets into a state of frustration. The student is occupying himself with the set task, but it isn't progressing as the student wants it to or as it should. There is motivation and the student is interested in the task, but there is a blockage -> something is limiting the student. This limitation can be external (e.g. a student is unable to remove the cap from a bottle) or internal (e.g. "I just don't get it!").

Signs: *frowning, tense posture, high physical activity (i.e. excessive restlessness, e.g. wobbling on a chair or continuously tapping the table), gaze direction is either completely towards the task or eyes go back and forth rapidly, verbal statements such as "It won't work!" or "How is this done?!" that reach a higher pitch in intonation at the end of the sentence, fluctuating distractibility (i.e. hyper-focus on the task interspersed with the tendency to focus on something else).*

4 – Interest

The student is actively involved with the set task, is concentrated and interested in the assignment.

Note: questions can be asked in other states of engagement as well. In 'active away behaviour' questions will not relate to the task; in 'boredom' a student may ask tiredly whether the task must really be completed; in 'resignation' a student may sigh and ask whether he needs more material to work with; in 'frustration' a student can ask why something isn't working in an irritated fashion. But not until 'interest' does a student ask calm and genuinely interested questions that are not affectively charged. The student seems open and relaxed. Reading an instruction out loud can be categorised as a '4' when this occurs at an expected pace, is not accompanied by sighs, is clearly enunciated (no mumbling), and when the student is difficult to distract while doing so.

Signs: *lightly bending forward over the table, stable eye-contact with the teacher, responsive to the teacher (gaze direction follows the teacher's when the teacher points to a certain aspect of the assignment), limited distractibility. The student often asks questions in order to clarify the task or to get a more elaborate explanation about something from the teacher.*

5 – Enthusiasm

The student is intensively involved with the set task and seems to be absorbed in it.

The student tells about his findings to the teacher or fellow students, often using a higher intonation, fast pace of speech, a lot of hand-gestures, and with a slight blush of excitement. The student may gaze intensively at the task-material when an experiment is being done, so as to not miss anything. Questions, however, are not usually asked when a student is in a state of enthusiasm -> the student is occupied with telling about or explaining the task or his findings. The excess physical activity present when in a state of enthusiasm is different from the restlessness present during states of frustration. It stems from wanting to do or say too much at once, and can therefore be differentiated by closely watching the accompanying affect. When coding a '5', the facial expression and posture that accompany the physical activity need to be open, and joy will often be clearly visible (i.e. a student is smiling and a gleam is visible in his eyes). When coding a '3', however, a frown and tense muscles generally accompany the physical activity.

Signs: *lots of smiling, open facial expression and posture, stumbling over words because the student wants to say too much too fast, high physical activity, initiating discourse, not distractible.*

A – Additional

The student expression fits none of the categories.

Appendix C

Video Feedback Coaching for teachers

For whom

The intervention aims at supporting teachers from elementary education in professionalizing science and technology education.

Goal

The Video Feedback Coaching program for teachers is a professionalization trajectory, i.e. educational intervention, designed to support teachers in improving the quality of science and technology lessons in their classroom.

We operationalized an improvement as an increase in complexity of students' scientific understanding. This is achieved by developing teacher's ability to recognize teachable science moments. These moments are opportunities to learn that arise when students are excited, engaged and primed to learn and the teacher seizes those moments to optimize scientific understanding.

An important goal of science and technology education is preparing students to engage in scientific reasoning in order to solve problems, develop explanations, draw conclusions, make decisions and extend knowledge to new situations. It is a way of teaching students a particular way of reasoning in order to increase their level of scientific understanding. During science and technology education, several scientific reasoning skills are practiced, which are likewise essential to become self-regulated learners and by that for full participation in modern society. The way teachers interact with students is regarded as a key to quality of the science and technology lessons. This pedagogical-didactic intervention is developed to stimulate change in teaching-learning processes. To achieve this goal the intervention focuses on achieving the sub goals described below. Each sub goal is theoretically embedded.

Improve knowledge about effective science and technology education

Science and technology education can take several forms. In the Netherlands an often used approach is 'onderzoekend en ontwerpend leren' (loosely translated as inquiry-based learning and learning by design) (SLO, 2015). Inquiry-based learning is a method in which students are actively engaged using both science processes and critical thinking skills as they search for answers (Gibson & Chase, 2002). A recent meta-analysis, indicated that students who actively engage in the learning process through scientific investigations were more likely to increase conceptual understanding than were students who experienced passive techniques (Minner, Levy, & Century, 2010). Inquiry-based learning asks for active learning opportunities for the students, hands-on activities that trigger students urge to explore and to manipulate. When provided, those activities can easily be used as a starting point to engage students 'minds-on' activities. Several pedagogical-didactical tools are known to support teachers:

Teachers can use the steps of the **empirical cycle** (figure 1) as a guideline to provide structure for hands-on activities (White & Frederiksen, 1998), like conducting experiments or design studies. At the same time, however, the steps of the empirical cycle can be considered as important clues for the thinking process, the minds-on activities. The empirical cycle should be understood as a method that helps teachers to accompany students in their processes of exploration and inquiry. The empirical cycle is not always realized in its entirety, nor do the phases always occur in a fixed order. Just like in “grown-up” science, the process of questioning, hypothesizing, experimenting, finding results, and further questioning is a continuously recurring cycle. Teachers can explicate each step of the empirical cycle by asking questions (Chin, 2006; Oliveira, 2010; Van der Zee & Minstrell, 1997; Wetzels, 2015). Asking about students hypothesis about what is going to happen is, for instance, known to stimulate students’ curiosity (Loewenstein, 1994). When predictions are actually tested, some outcomes are as predicted and other outcomes are not as predicted. Especially, when the outcome violates student’s hypotheses, students’ curiosity, i.e. the experience of a gap in their understanding, is triggered. Curiosity is an important element of, or engine for, scientific understanding to occur (Engel, 2006).

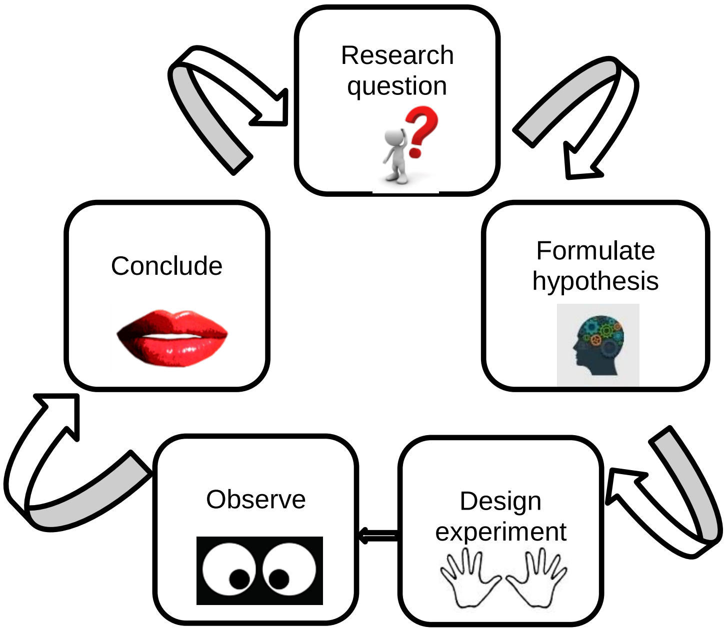

Figure 1 Empirical cycle

Questioning skills are the second important teacher characteristic. Several studies state that teachers use questioning often as a means of keeping attention focused, a so called organizational tool (Chin, 2006). However, questions can be used as an important aid to spark and maintain curiosity and interest and to stimulate the thinking processes and by that their understanding of scientific concepts (e.g. Barber & Moursched, 2007; Chin, 2006; Oliveira, 2010). Posing thought-provoking questions requires insight in students thinking processes. Posing a question which is outside the student’s zone of proximal development (Vygotsky, 1986), will not be beneficial for learning.

Scaffolding students thinking processes and understanding (Wood, Bruner, & Ros, 1976; Van de Pol, Volman, & Beishuizen, 2010) is therefore considered as the third essential skill. Scaffolding usually starts with a student-centered question (Van de Pol et al., 2010); after all, a teacher needs to know what a student already knows and about what part of the assignment (s)he needs help. However, scaffolding is not only a way to help students who explicitly ask for help. It is a way to help student towards taking increasingly more responsibility for their own learning processes (i.e. become self-regulated learners). The teacher can for instance, throw the responsibility of thinking back at a student by asking, what do you think? This implies less teacher support in the form of explicit instruction and information (fading, Van de Pol et al., 2010). The role of the teacher becomes more like a coach. Note that although these three teacher practices are described as separate skills, they all work at the same moment to stimulate students' scientific understanding. The goal is then that students are stimulated to develop critical thinking skills in such a way that they become self-regulated learners, i.e. they become increasingly responsible for their own learning progress.

Strengthen skills

Strengthening skills of teachers is a specific form of **behavioral change**. The assumption we consider is that an observable increase in students' scientific understanding can be brought about by improving the skills of the teacher. We view science and technology learning as a process. Learning in the classroom occurs in interaction and should be conceived of as a socially embedded process in which teacher, students and material mutually influence each other (Steenbeek & Van Geert, 2013; Figure 2).

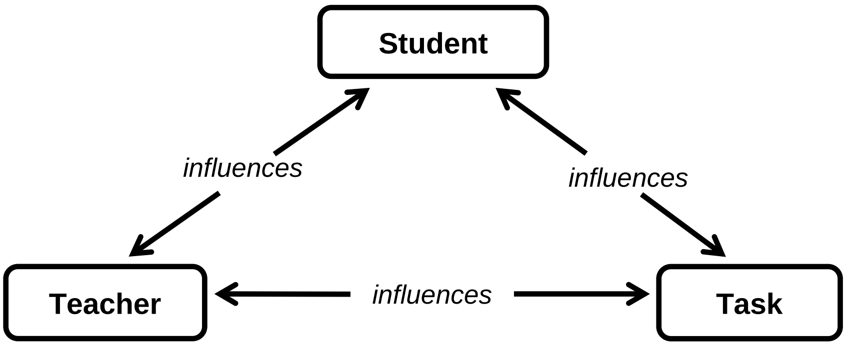

Figure 2 Triangle which shows the reciprocal relations between adult, student and task

An idiosyncratic approach is needed to strengthen teacher's practice for several reasons. First, each teacher functions in a different system (each classroom is unique, each school is unique). Second, each teacher has its own baseline level. For some teachers this means that strengthening skills consists of acquiring a new set of skills, while it for other teachers implies using their existing skills in a different way, for instance by specifically adapting it to students' needs. The focus is thus on concrete actions in the actual teaching-learning situation. Several studies show that a combination of theory, practice and critical reflection best supports behavioral change (e.g. Fabiano et al., 2013). The VFCt consists of such a combination:

Theory will be provided about which strategies are considered to be effective (i.e. the pedagogical didactical tools described above) in providing science and technology education. However, knowing something from theory does not mean that it can be applied in practice. Therefore the above mentioned teacher practices are applied to classroom settings.

First, according to Lehman and Gruber (2006) expertise can best be acquired through **case-based learning**, including authentic cases which are embedded in naturalistic contexts. Therefore, several best-practice video fragments of student-teacher interactions during science lessons were shown to illustrate the transactional nature of performance; i.e. the importance and effect of high quality interactions during science and technology-activities. So, best practice examples are used to show what strategies can be used and what the effect is on students functioning.

Second, it is important that teachers **practice** their skills in their own learning environment. Practice is highly effective when combined with immediate feedback on the behaviors (Fukkink, 2005). A promising method for implementing evidence-based instructional strategies, i.e. establishing behavioral change, is providing feedback on real-time behavior (Reinke, Sprick, & Knight, 2009; Noell et al., 2005). Teachers instructional quality can be greatly increased by offering video feedback of own classroom behaviors (see also Mortenson & Witt, 1998; Seidel, Stürmer, Blomberg, Kobarg, & Schwindt, 2011; Wetzels et al., 2016). In this way powerful, i.e. effective, instructional strategies can be identified and applied to situations which are in need of improvement.

Third, by reviewing interactional sequences, teachers become aware of the influence their behavior has on students (participation). Teachers' awareness of their own role is an important indicator for the quality of their support, which is a crucial factor in improving students' learning (Barber & Mourscheed, 2007; Mercer & Dawes, 2014).

Support long-lasting behavioral change

In order to support long-lasting behavioral change, i.e. new behavioral patterns of teacher's practice and students' behavior, it is important that teachers are intrinsically motivated to change. Intrinsic motivation is important as it energizes and directs behavior (Reeve, 2002). In order to flourish, teacher motivation needs supportive conditions. This means, for instance, establishing supportive teacher-coach relationships but also feeling acknowledged by colleagues. The coach's role is to support teacher motivation that is already there. According to the self-determination theory, three needs are important as a source of teachers' tendency to extend their capabilities, explore, and learn (Ryan & Deci, 2002).

The first is feelings of *autonomy*. Teacher experience feelings of autonomy if opportunities are afforded to them in which they have a sense of psychological freedom, and perceived choice in their actions. Goal setting at the beginning of a coaching trajectory is an effective way to achieve results (Hock, Schumaker, & Deschler, 1995), as they ensure feelings of autonomy (Pintrich, 2000). By formulating learning goals, that reflect teacher's personal desire to professionalize, teacher's feelings of autonomy were respected and teachers were provided with opportunities to monitor and control their motivation and behavior. Another way to ensure teacher's feelings of autonomy and thus to create more responsibility for their own learning process, was by encouraging them to prepare science and technology lessons to his or her own liking. Highly specified curriculum materials might limit teachers' autonomy about what and how to teach (Coburn, 2003; Ede, 2006).

Second, feelings of *competence* refer to the need to be effective in, for instance, one's interaction with the environment. By means of critical reflection of own behavior, teachers are made aware of their strengths. As a rule, the effect of feedback is best when a 3 to 1 ratio is used (Fredrickson, 2015), i.e. three positive fragments were discussed and one fragment which could be improved. The coaching was conducted immediately after each lesson, as immediate feedback is most beneficial for learning (Fukkink, Trienekens, & Kramer, 2011). In addition, by offering teachers specific content-related tools about teaching science and technology teacher's competence can be strengthened.

Third, feelings of *relatedness* reflect the desire to be emotionally connected and interpersonally involved in responsive relationships. Relatedness is important on three levels. First, it is expressed in teacher-student interaction by purposely investing in more open and responsive interactions. Second, it can be expressed in teacher-coach interaction and third in teacher-colleagues interaction.

Relevance

Scientific understanding becomes increasingly important in society, which highlights the importance of starting at a young age to acquire these skills. Today’s society makes increasing demands on citizens. Technical highlights follow each other rapidly. In order to be able to keep up this pace it is important that all people learn how to approach the world of science and that more people flourish in science and technology related fields. This means that all children should be educated at primary education. However, nowadays, this is hardly ever the case. On average, science and technology related activities are emphasized in only 3% of the total educational time in the Netherlands (Verkenningscommissie wetenschap en technologie primair onderwijs, 2013). The committee states that this percentage should at least be doubled. The objective is that all primary schools structurally implement science and technology in their curriculum by 2020. However, teachers often feel incapable of teaching science and technology (Van Aalderen-Smeets, Walma van der Molen, & Asma, 2012). The committee therefore stresses the need to train teachers in the methodology of inquiry-based learning and learning by design (SLO 2015; Techniekpact, 2013). This committee assumes that science and technology activities meet children’s curiosity. A more prominent share of science and technology in the curriculum is considered to enrich educational practice. In addition, it is thought to better meet the demands of current society. In the long run, this approach is considered to increase the number of students starting technological training and professions.

One initiative is Curious Minds (in Dutch: TalentenKracht, founded in 2006 by Van Benthem, Dijkgraaf, & De Lange, 2005). Curious Minds is a research program including 7 universities, six being Dutch universities and the other Belgian, focusing on children’s knowledge and skills in science, technology, engineering, and mathematics (STEM) disciplines and studying how the abilities in STEM fields of these children can be advanced optimally making use of environmental factors such as teacher, parents and objects or activities. The program aims at professionalizing science and technology education by bridging research and practice. The starting point of this program is that each child is naturally curious and therefore talented in the STEM field. Talent is seen as a developmental and dynamic property which is visible in a child’s behavior. An important characteristic is the child’s heightened ability to learn, in which he makes use of his environment (people and equipment) and the processing includes deep level learning. Talented behavior also means that a child is capable of thinking of an original strategy to solve problems and is convinced of his own learning potential. Besides a powerful drive to learn, enjoyment and positive appreciation are important. This talented behavior reveals itself in skills such as questioning, exploring, critical thinking, reasoning and problem solving which is common behavior in young children and all skills necessary for a good researcher. Unfortunately, these skills seem to vanish when children grow older, which leads to few students choosing beta-studies and consequently, a shortage of professionals on the labor market. As talent is, in our view (Van Geert & Steenbeek, 2007), an ongoing transactional process between the child and the environment, we argue that teachers can make a difference and slow down (or reverse) the decreasing interest in science and technology, and elicit talented behavior. Talented behavior might become visible during interactions in which the child is enabled to reach excellence in the science and technology domain, to learn from rich educational contexts and to elicit rich educational interactions from their teachers. However, this is only possible when their teacher is capable of recognizing and subsequently stimulating the curiosity and interest of the child in the science and technology domain. The talent process is the one that maximizes the potential of the individual.

The department of developmental psychology at the University of Groningen, which is one of the participants of the Curious Minds research program, has theoretically grounded its Curious Minds projects in the theory of co-construction (in line with a complex dynamic systems theory; Fischer & Bidell, 2006; Thelen & Smith, 1994; Van Geert, 2003). That is, as children construct scientific understanding about a specific problem, they do so together with an adult or another child (Sorsana, 2008). We, as coach and teacher, observe and analyze the dynamics of this co-construction process in naturalistic situations, such as the classroom. This creates more insight into how young children's scientific curiosity, creativity and reasoning develop and how teachers can optimally encourage these skills.

Transfer of skills

The pedagogical-didactical strategies and scientific reasoning skills acquired during this intervention are not restricted to science and technology education. The focus is on developing 21st century skills, which are relevant for life-long learning, but which are naturally evoked and displayed during science and technology activities. In addition, scaffolding principles are important skills to differentiate the learning process for learners (Van de Pol et al., 2010), regardless of a specific topic. The approach of stimulating self-regulated learning can be applied in all teaching-learning processes, but can be practiced best during science and technology education. Science and technology-education provides a naturalistic inquiry based situation and ample opportunities for teachers to stimulate students' active participation in co-constructing effective learning situation and by that increase higher order thinking in students.

Design

The intervention is implemented on the classroom level. The focus is on teacher's practice. The intervention was implemented as a relatively short and cost-effective approach. Figure 3 shows the design of the intervention. The methodology consists of theoretical background in combination with practice of evidence based pedagogical-didactical tools to improve educational quality. Teachers gain insight into students' scientific reasoning capabilities (i.e. their level of scientific understanding and their motivation in science and technology related activities). In addition, they gain insight in their own role in the teaching-learning processes during science and technology education. In particular, teachers gain insight into those interactions that improve or hamper students' development of scientific understanding.

Initially this intervention has been designed for lower grade teachers (Wetzels, 2015). However, whereas in grade 1-4 the teacher needs to ask relatively easy questions to stay within the zone of proximal development of the child, it becomes more complex for the grade 5-8 teacher to ask questions that heighten students' reasoning skills. The complexity of students' cognitive reasoning and understanding becomes higher and more diverse, making the co-construction of meaningful learning situations considerably more demanding. Although the intervention is highly similar to the lower grade intervention in terms of evidence-based effective elements, coaches should tailor the implementation of the intervention to upper grade teachers. Based on the pilot study it was considered important to provide explicit guidelines for the design lessons. In addition, a discussion about what the role of content knowledge is helps teachers to see the value of pedagogical-content knowledge and the importance of modeling inquiry attitudes themselves. Lastly, the role of thought-provoking follow-ups should be one of the main strategies. Initiation question seemed to evoke students' participation. Follow-up questions stimulated higher order thinking skills as the responsibility for the thinking process is at the student.

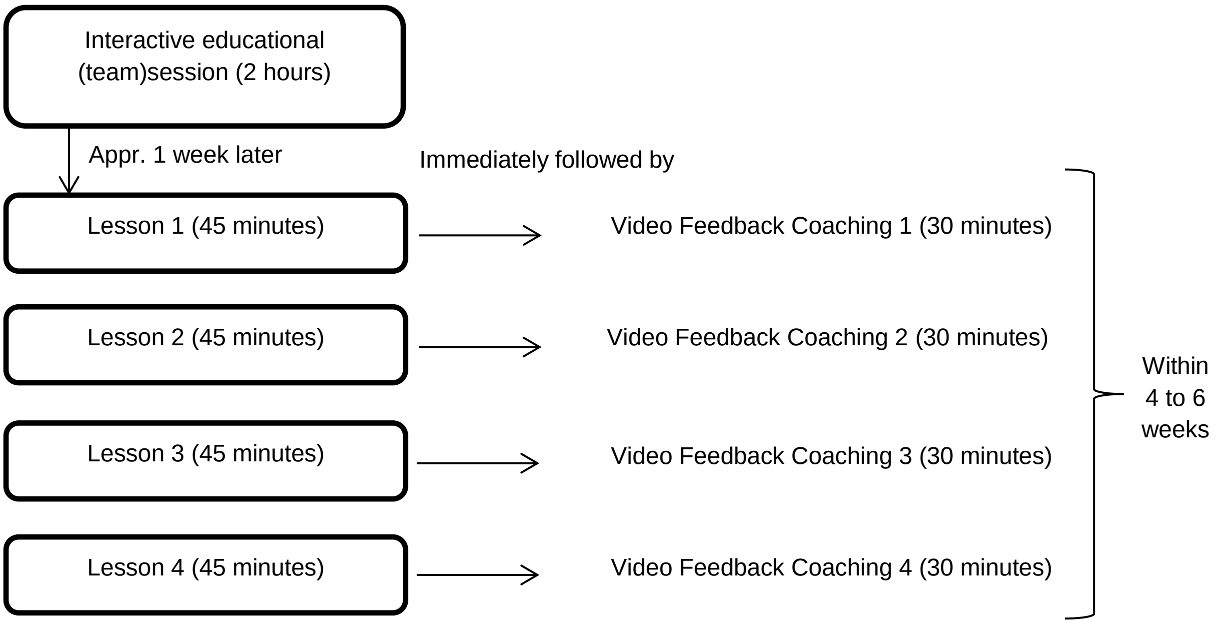

Figure 3 Schematic presentation of intervention design. The content of each video feedback coaching sessions is dependent of each teacher's learning goal

Interactive educational (team) session

The intervention is carried out by a trained coach (see train de trainer; Wetzels, Steenbeek, & Fraiquin, 2011). Before the coach enters the classroom, the teacher will be trained. During an interactive educational session about knowledge of inquiry-based teaching and scientific skills, participating teachers were informed about effective instructional strategies. Osborne (2014) defined these skills as knowledge about the process of science – including knowledge about the empirical cycle - and the skills needed for performing an actual scientific inquiry – such as higher order thinking skills. During this educational session information was provided and the features important for science learning were discussed: the use of the empirical cycle (De Groot, 1994), use of thought-provoking questions (Chin, 2006; Oliveira, 2010), scaffolding (Van de Pol et al., 2011), and science and technology-education in general (Gibson & Chase, 2002). Next, several best-practice video fragments of student-teacher interactions during science lessons were shown to illustrate the transactional nature of performance; i.e. the importance and effect of high quality interactions during science and technology-activities. We therefore used fragments of teachers own lessons (as recorded during a premeasure). One reason was to familiarize teachers with the process of critical reflection. Another reason was to provide them with specific information about their own practices. This means that the theoretically framework provided was displayed using fragments of their own practice, i.e. show how they already use (some) elements in their current teaching practices.

Coaching

The aim of the intervention is to support teachers to recognize, stimulate and evoke talents of students. The coach offers tools, in terms of theoretical knowledge as well as practical skills, to shape science and technology education in such way that the talents of each student are stimulated. The coaching specifically focuses on teacher's practice. Teacher can evoke students thinking by employing an inquiry attitude themselves and by using the steps of the empirical cycle. Video feedback coaching is used as coaching methodology. This means that the teacher will be coached using video fragments of their own science and technology lessons. The scope of the coaching concerns those pedagogical-didactical skills important for stimulating scientific understanding; as a consequence the coach refrains from feedback on other didactics.

The coach records each lesson. One camera is installed in the back of the classroom to provide an overall impression of each lesson (back-up camera). The coach holds the other camera. The recording of this camera is used for video feedback coaching. This camera is connected with a remote Bluetooth microphone attached to the teacher. The microphone is used to remove background noise and optimize the recording of teacher-student interaction. A consequence of a whole class setting is that the coach cannot always hear the interaction between specific teacher-student pairs while sitting at the back of the classroom, as other students are working and talking in small groups themselves. In order to be able to provide video feedback immediately following each lesson it is essential to hear what teachers and students say. As a consequence, the coach follows the teacher around the classroom, at an appropriate distance. The camera is always focused at the teacher.

The coaching sessions

Individual coaching sessions are designed to (further) develop the ability of a teacher to recognize student's talented scientific acting and thinking. During the debriefing, the focus is on the learning process, with accompanying learning goals, of the teacher. The coach helps to achieve these goals by providing targeted feedback. The main focus is on concrete actions during teachable science moments. What is most important is that teachable moments only occur when teachers observe, recognize and act according to the (spontaneously) occurring interest of learners. Such (missed) moments will be selected by the coach during the lesson and discussed using video fragments. The main focus is on approximately three moments in which the teacher properly, i.e. stimulating, responds to talented behavior of the children. In addition, to stimulate the learning, one moment will be discussed in which more talented behavior could be elicited. The video fragments are used to illustrate the effectiveness of teacher-student interactions to improve educational quality.

The coaching sessions starts with the coach asking the teacher to shortly summarize how (s)he experienced the lessons and how well the learning goal was implemented. Next, several moments will be discussed in which the coach shortly introduces which moment of the lesson will be discussed and how it is related to the teacher's learning goal. After viewing the fragment the teacher is asked to reflect on the fragment and discusses with the coach their perspective of the effectiveness of the interaction. After reviewing several fragments the coach asks the teacher whether (s)he needs to reformulate the learning goal to be more specific or whether the learning goal has been accomplished. If the teacher is satisfied with the progress, the coach encourages the teacher to formulate a new learning goal.

Curious Minds principles

This intervention is based on five Curious Minds principles (Steenbeek & Van Geert, 2009):

1. Everyone is talented and can develop her talents in interaction with her environment.
2. Young children show curiosity for their environment, the challenge for adults is to make it flourish.
3. Teachers have the ability to see, recognize and stimulate talented science and technology behavior, position this behavior within a developmental perspective, and act accordingly.
4. Teachers can develop themselves as 'teaching experts' and as 'talent-experts'.
5. You learn by case based learning.

More practical, it is possible to see talented behavior by carefully observing students, but also by means of viewing best-practice examples of other teachers. It is important to be able to place the behavior within the student's zone of development and thus be able to scaffold a student to higher levels of functioning. It is further important to consider each student as talented. This means that high expectations are expressed for every student. Teachers can stimulate students to express talented behavior by providing challenging activities and by improving interaction with others. In order to achieve this, it is important to practice these skills and attitudes.

For coaches the same principles apply, but now instead of student, teacher should be read. This means that the coach addresses the teacher like the teacher is supposed to approach students. Specifically, this means that the focus in on talented behavior of the teacher in the class situation.

Material

Materials shown below are developed for the purpose of the Video Feedback Coaching for teachers and can be found on www.talentenkrachtgroningen.nl.

1. Teacher workbook (for lower grade and upper grade teachers)
2. Train de trainer module (for coaches)
3. Flashcards (several versions of how to use the empirical circle using questions in such a way that evoke higher levels of scientific understanding)
4. Best practice examples (in text or video fragments)
5. Tips for science and technology lessons (formulated as hip pocket solutions that help teachers recognize cognitive levels of complexity of students, and ask questions in such a way that actually higher cognitive functioning is promoted)

Research

Several studies started to implement the Video Feedback Coaching trajectory in different settings. One study focused on the effects of the Video Feedback Coaching in lower grades of elementary education (Wetzels, 2015), another study specifically focuses on effects of language development (Menninga, Van Dijk, Cox, Steenbeek, & Van Geert, 2016), one study has started in schools with children with special educational needs (Honingh, 2013), and one study focused on the effects of the upper grades of elementary education (this dissertation). So far, one study established the effects of the Video Feedback Coaching for lower grade teachers and evidence for the effectivity of this intervention for the upper grades of elementary education can be found in the chapters of this dissertation.

Lower grades of elementary education (Wetzels et al., 2015)

Six kindergarten teachers participated in the VFCt and five teachers functioned as control condition. Each teacher used a subgroup of students – to be better able to practice skills in small group (and for practical reasons to be better able to record data). The effect was measured in the classroom in combination with interviews with teachers. The information of the interviews showed that teachers reported that their well-being and motivation increased. They mentioned four reasons for this: 1. Better preparation of the science and technology lessons, 2. Increase of knowledge of science and technology, 3. Better interaction with their pupils during the lessons, and 4. Better science and technology teaching as a result of the coaching. The measures in the classroom showed gains in scientific understanding of the pupils. Although teachers did show changes during intervention, this did not last at post-measure. During the intervention, the amount of scientific reasoning eliciting questions increased significantly. No such changes were found for the control condition.

Upper grades of elementary education (Van Vondel et al., 2016)

In a nutshell, attitudinal change as measured with the validated DAS questionnaire for teachers in the intervention condition were found, while no changes were found for the control condition (chapter 5). By focusing on observational measures a change in students' behavior was found, in that more and more complex scientific understanding was displayed (chapter 3; 4). In addition, chapter 4 showed that the interactional pattern after the intervention consisted of more thought-provoking teacher's practice and more complex level of scientific understanding in students when they co-construct scientific understanding. Preliminary evidence for effects of the intervention on students' enthusiasm was found (case study; chapter 6). No change in students test scores concerning scientific knowledge as measured with and established CITO test (chapter 3) or change in students' attitude towards science and technology was found that could indicate an intervention effect (chapter 5).

Conditions

Above, the importance of intrinsic motivation is discussed. In addition, it is important that there is support for implementing science and technology in the curriculum. Ideally, all teachers from one school start implementing science and technology. Experience shows that interventions work best when several teachers from the same school participate; this is to establish a school wide supported vision. It is important that the policy concerning implementation of science and technology is supported school wide as it will benefit the maintenance of the newly learned skills. In this way a learning process can be established that transcends all academic years of primary education. In addition, colleagues can stimulate and support each other in implementing a new approach in their classroom and provide assistance if needed.

Implementation

The intervention demands a lot of the teacher. They are confronted with their own behavior. They often need to use 'other glasses' to look at students. They are encouraged to use another pedagogical-didactical approach in which they become more of a coach instead of an expert. They are stimulated to provide inquiry-based lessons, which often imply less structured lessons. This intervention intends to boost teachers to get started with science and technology. After the intervention the teachers are expected to further improve their skills by proceeding to provide science and technology lessons.

Output

Results about the effectiveness of the intervention are published in both academic and practice-based journals. Further details of the intervention, publications and information about the Curious Minds project can be found on www.talentenkrachtgroningen.nl. The founders of this intervention offer the VFCt via www.coachinginhetonderwijs.nl. Furthermore, in cooperation with the university of applied sciences an online-module including an online coaching-platform has been developed (more information via l.schrage@pl.hanze.nl).