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Transformation of topic-specific professional knowledge into personal pedagogical content knowledge through lesson planning

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ABSTRACT

This study investigates the relationship between two different types of pedagogical content knowledge (PCK): the topic-specific professional knowledge (TSPK) and practical routines, so-called teaching scripts. Based on the Transformation Model of Lesson Planning, we assume that teaching scripts originate from a transformation of TSPK during lesson planning: When planning lessons, teachers use their TSPK to create lesson plans. The implementation of these lesson plans and teachers' reflection upon them lead to their improvement. Gradually, successful lesson plans are mentally stored as teaching scripts and can easily be retrieved during instruction. This process is affected by teacher's beliefs, motivation and self-regulation. In order to examine the influence of TSPK on teaching scripts as well as the moderating effects of beliefs, motivation and self-regulation, we conducted a cross-sectional study with $n = 49$ in-service teachers in physics. The TSPK, beliefs, motivation, self-regulation and the quality of teaching scripts of in-service teachers were assessed by using an online questionnaire adapted to teaching the force concept and Newton's law for 9th grade instruction. Based on the measurement of the quality of teaching scripts, the results provide evidence that TSPK influences the quality of teaching scripts. Motivation and self-regulation moderate this influence.

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Beliefs; motivation; topic-specific professional knowledge; self-regulation; quality of teaching scripts; lesson planning

1. Introduction

The question of what teachers need to know in order to design high-quality instruction is a holy grail of teacher education research. Nearly every study on professional knowledge of teachers focuses on Shulman's conceptualisation (1987) of pedagogical content knowledge (PCK) as the knowledge base for teachers designing their lessons (Baumert et al., 2010; Cochran, DeRuiter, & King, 1993; Gess-Newsome, 1999; Grossman, 1990; Magnusson, Krajcik, & Borko, 1999; Shulman, 1986). However, there was little consensus on what PCK is. Past studies differ considerably in the number of components included in the definition of PCK and in the description of these components (Cochran et al., 1993; Grossman, 1990; Hashweh, 2005; Loughran, Berry, & Mulhall, 2012; Magnusson et al., 1999;

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Park & Oliver, 2008). This led to an increasing amount of incompatible research results and undefined impacts on students' achievements.

As a consequence, an international group of researchers recently started a first attempt to develop a model that would integrate these different approaches – the model of teacher professional knowledge and skills (TPK&S Model; Berry, Friedrichsen, & Loughran, 2015). At the centre of teachers' professional knowledge, PCK is still seen as a central knowledge base (Gess-Newsome, 2015). However, the innovation is a differentiation between topic-specific professional knowledge (TSPK) on the one hand and personal PCK as well as skills on the other. TSPK is assumed to be canonical and generated by research or best practice, with a normative function for teacher education programmes. In contrast, personal PCK is viewed as tacit, person- and situation-specific. It can be used more effectively and flexibly in the communication process between teachers and learners during classroom practice than TSPK. It is assumed that TSPK influences personal PCK, but that this influence is amplified or filtered by teachers' beliefs, their motivation to teach or their self-efficacy during teaching (Gess-Newsome, 2015).

In this study, we investigate the transformation of TSPK into personal PCK as a cognitive process driven by lesson planning. We propose a model for describing this transformation process based on a synthesis of the Adaptive Control of Thought (ACT)*-Theory by Anderson (1983) and the model of teachers' decision-making processes by Shavelson and Stern (1981). According to the latter model, teachers come to personal decisions during lesson planning based on their TSPK, beliefs, motivation and self-efficacy. These decisions manifest with time and with an ongoing reflection on the results and the adaption of decisions during lesson planning as teaching scripts – representative knowledge structures of teachers' personal PCK. Hence, lesson planning can be assumed to be a driving mechanism in the transformation of TSPK into teaching scripts. Based on our model, we tried to find evidence for the relationship between teachers' TSPK, the assumed amplifiers and filters as well as their teaching scripts. For this, online questionnaires were administered to in-service teachers ($n = 49$). The analysis of our data was conducted using the partial least square structural equation modelling (PLS-SEM) approach and the results support nearly all of our assumptions.

2. Theoretical background

Nearly every model describing relevant teachers' knowledge is based on Shulman's conceptualisation (1987) of what might constitute a knowledge base for good teaching. Within his conceptualisation, Shulman assumes subject matter knowledge (SMK), pedagogical knowledge (PK) and pedagogical content knowledge (PCK) as the relevant knowledge for teaching and as reflecting the results of teaching. In particular, he highlights PCK as being the unique knowledge base for teachers: their own special form of professional understanding (Shulman, 1987).

2.1. PCK – a unique knowledge base of teachers

The underlying idea of PCK is that this knowledge distinguishes teachers from experts in the discipline they teach. This idea caught the attention of many researchers who wanted

to explore and describe the structure of this unique knowledge for good teaching (Cochran et al., 1993; Grossman, 1990; Hashweh, 2005; Loughran et al., 2012; Magnusson et al., 1999; Park & Oliver, 2008). It is the transformation of subject matter knowledge for the purpose of teaching that constitutes PCK across all conceptualisations. However, two main differences can be identified in these conceptualisations. One occurs with respect to the constituent components of PCK (Park & Oliver, 2008). The core components of PCK (knowledge of instructional strategies, students' understanding and subject matter) are often extended with components depending on the conceptualisation of PCK (knowledge of the curriculum (Grossman, 1990; Magnusson et al., 1999); knowledge of assessment (Hashweh, 2005; Magnusson et al., 1999); knowledge of the context (Hashweh, 2005; Loughran et al., 2012)).

Another difference deals with the question whether PCK is commonly accepted as canonical and normatively defined by researchers (Kirschner, Borowski, Fischer, Gess-Newsome, & von Aufschnaiter, 2016; Kunter et al., 2013), or a personal, unique and context-specific knowledge that teachers develop during the interactions in real classroom settings (Brovelli, Bölsterli, Rehm, & Wilhelm, 2013; Henze & van Driel, 2015).

Despite all efforts to portray and capture PCK, a considerable divergence remains in the interpretation of the construct and its impacts on students' learning (Carlson, Stokes, Helms, Gess-Newsome, & Gardner, 2015). Based on the diversity of PCK models and the dissatisfaction with the non-existence of a shared conceptualisation of the construct of PCK, researchers jointly re-examined PCK during a summit and developed a new model for teacher professional knowledge and skills (Berry et al., 2015).

2.2. The new conceptualisation – teacher professional knowledge and skills

The TPK&S Model, as a first attempt to combine the diverse conceptualisations of PCK, differs considerably from earlier models of teacher professional knowledge and competence (see Figure 1). The new aspect is a differentiation between topic-specific professional knowledge (TSPK) and personal PCK (Gess-Newsome, 2015). TSPK is seen as canonical, defined by researchers or best practice and as being necessary for good teaching of a specific topic for a specific developmental level of students (Gess-Newsome, 2015; Veal & MaKinster, 1999). The content representations (CoRe) developed by Loughran et al. (2012) are an example of TSPK. These CoRes represent the knowledge a community of teachers defines as relevant for teaching a topic at a given grade level. For example, there are commonly accepted, mostly declarative statements about students' learning difficulties in understanding the concept of force and motion on the 9th grade level in physics. (Hashweh, 2005; Kirschner et al., 2016; Magnusson et al., 1999; Park & Oliver, 2008). In comparison to this knowledge type, personal PCK is clearly defined as the personal knowledge of the teacher. This includes knowledge for teaching a particular topic in a certain way for a specific purpose to particular students. It occurs explicitly during the pre-active planning and post-active reflection on action and explicitly or tacitly during the interactive decision-making during reflection in action (Gess-Newsome, 2015; Schön, 1983).

According to the conceptualisation of teachers' professional knowledge shown in Figure 1, personal PCK is the central knowledge that teachers' decisions rely on during

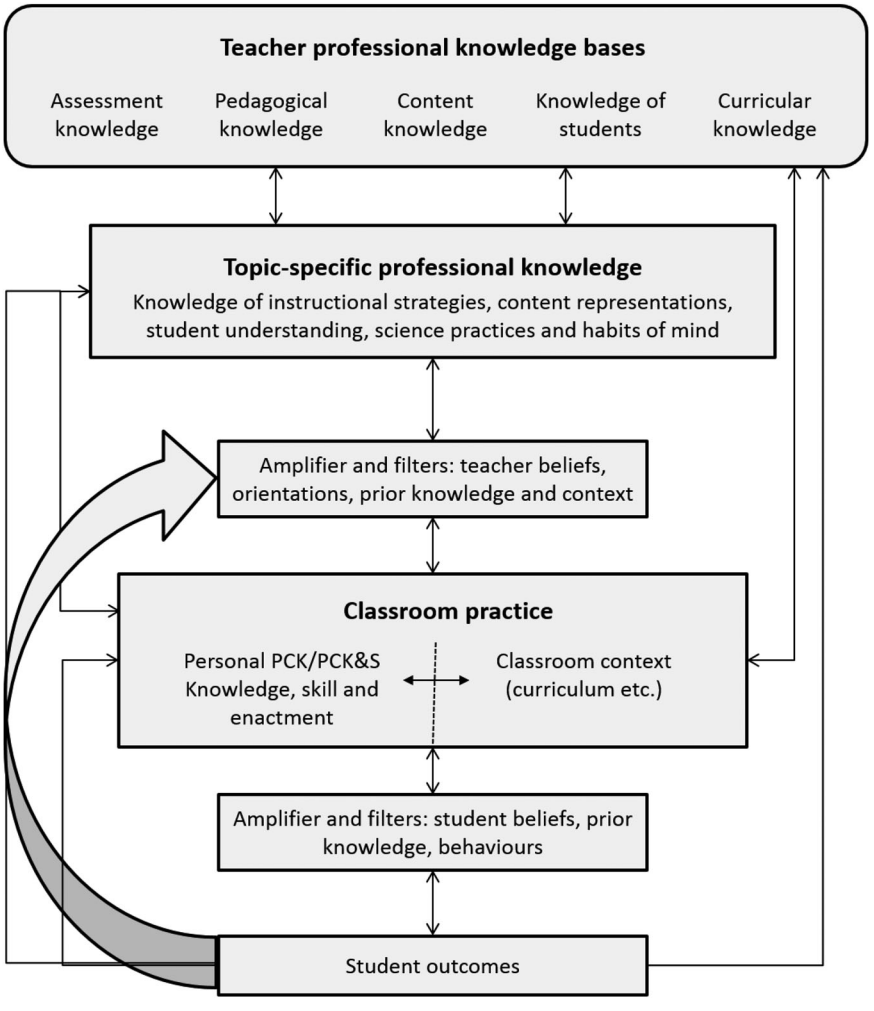

Figure 1. Model of teacher professional knowledge and skills that includes PCK (Gess-Newsome, 2015).

instruction and which at best is derived from TSPK. Teachers' beliefs, their motivation as well as their self-efficacy or other affective dispositions can influence which TSPK has relevance during teachers' decision-making processes and, therefore, which personal PCK a teacher develops over time. These affective dispositions can serve as both amplifiers and filters. Although this model assumes a relation between TSPK, personal PCK and teachers' affective dispositions, the model lacks an explanation for the transformation process of TSPK into PCK. In order to fill this theoretical gap, we developed a model which describes the transformation process from TSPK to personal PCK.

2.3. The transformation from TSPK to personal PCK&S

The TPK&S Model differentiates between TSPK and personal PCK. TSPK is canonical, generated by research and has a normative function in terms of what teachers have to know (Gess-Newsome, 2015). Novices in teaching acquire this type of professional

knowledge in initial teacher education programmes or generally speaking, during the academic part of teacher training. This knowledge, first acquired by studying theories for good teaching detached from self-experience in real classroom situations, remains as mental propositional structures, which cannot be easily retrieved for pre-active decisions and even less for interactive decision-making during instruction (Anderson, 1983; Shavelson, 1986). On the contrary, personal PCK becomes explicitly important during the pre-active planning and the interactive decision-making of experienced teachers (Gess-Newsome, 2015). Due to the easy retrievability of personal PCK for spontaneous decisions, it must be represented by mental structures other than propositional ones (Schank & Abelson, 1977). Shavelson (1986) assumes that this knowledge is stored as teaching scripts (see also Schank & Abelson, 1977). These teaching scripts can be regarded as mental representations of familiar, everyday experiences in teaching situations. Teaching scripts are procedural knowledge structures that represent spatio-temporal knowledge about students and sequences of events in classroom settings that are acquired with teaching experience (Borko, Roberts, & Shavelson, 2008; Henze & van Driel, 2015; Shavelson, 1986). Combining these assumptions with the TPK&S Model, one can assume that teaching scripts, as cognitive structures for personal PCK, originate from propositional knowledge structures of TSPK (Gess-Newsome, 2015).

For this influence of TSPK on teaching scripts to be effective, a complex transformation process of complex transformation process of propositional knowledge into procedural knowledge must take place. According to the ACT*-Theory from Anderson (1983) this transformation takes place in three phases. In the first phase, the interpretation phase, pre-service teachers consider theories for good instruction in unspecific situations detached from actual classroom contexts in pre-service teacher training situations. In this phase, teachers develop and consolidate TSPK. In the second phase, the compilation phase, pre-service teachers transform their TSPK into lesson plans for specific teaching situations. As a free agent, a teacher has the opportunity to reject using instructional strategies or to modify organisation of the content for his or her needs. In fact, Bromme and Tillema (1995) found out that many teachers perceive a gap between their TSPK and the requirements of teaching (Fischler, 2008). Potentially, essential TSPK is available, but teachers are not convinced that this knowledge has a positive benefit in practice (Gess-Newsome, 2015; Renkl, 1996). Thus, the knowledge is not used during lesson planning. In addition, a teacher's motivation or self-efficacy can influence what he or she chooses to implement in the lesson (Gess-Newsome, 2015; Renkl, 1996). Therefore, teachers' beliefs, motivation and self-regulative skills act as amplifiers or filters in the transformation process of TSPK into lesson plans. In the last phase, the tuning of lesson plans, teachers retain or modify their lesson plans and internalise their lesson plans as teaching scripts. In detail, teachers implement the lesson plans during instruction and reflect upon the consequences for students (Borko et al., 2008; Shavelson & Stern, 1981). Lesson plans that work as expected for students' learning are endorsed; lesson plans that do not run smoothly will (ideally) be adapted in future lesson planning. With time, successful lesson plans, which teachers can easily retrieve during spontaneous pre-active and interactive teaching situations, are mentally saved as teaching scripts (Shavelson, 1986). An influence of teachers' TSPK on teaching scripts as personal PCK should have formed during this transformation process (see Figure 2). Besides teachers' TSPK, their

beliefs, motivation and self-regulation have a moderating effect on the influence of TSPK on teaching scripts.

The teaching scripts developed and tested in real classroom situations enable experienced teachers to outperform novice teachers in noticing meaningful instructional details, interpreting them and identifying alternative strategies for solving occurring problems during instruction (Berliner, 1986; Borko & Livingston, 1989; Livingston & Borko, 1989). For other domains than teaching, this routine in action bases on scripts which are easily retrievable, show high dependency of decisions and high concreteness (Bransford, Brown, & Cocking, 2000). We assume that these formal features of teaching scripts (retrievability, high dependency and concreteness) also predict to what extent teaching scripts enable teachers to act in a routine way in teaching situations (see Figure 3). However, routine does not directly indicate high-quality instruction. Rather, the teaching scripts have to fulfil functional features. For example, appropriateness of decisions to antecedent conditions is seen as a feature predicting instructional quality (Shavelson & Stern, 1981). Coherence of decisions for instruction is seen as a second feature (Seidel, Rimmele, & Prenzel, 2005). The third feature characterises the potential of the script to cognitively activate the students during classroom instruction, an aspect that also has to be considered during lesson planning (Kunter et al., 2013; Lipowsky et al., 2009). It is thus assumed that these three functional features describe whether or not the teaching scripts can lead to a high instructional quality.

The presented transformation model of TSPK into teaching scripts through lesson planning represents a theoretical framework that specifies the transformation process assumed in the TPK&S Model by Gess-Newsome (2015). In contrast to the TPK&S Model it supplies specific assumptions on how the teachers' TSPK influences their personal PCK, mentally represented as teaching scripts. According to the Transformation Model of Lesson Planning, we assume that an influence of teacher's TSPK on teaching scripts evolves by lesson planning. However, whether teachers' TSPK influences their teaching scripts depends on the respective teachers' affective dispositions, such as their beliefs, motivation and self-regulation. Formally speaking, a teacher's affective dispositions

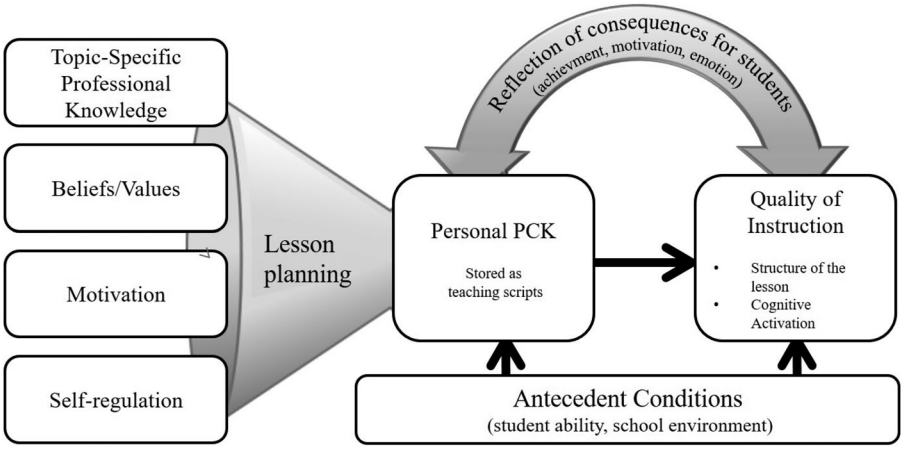

Figure 2. Transformation Model of Lesson Planning.

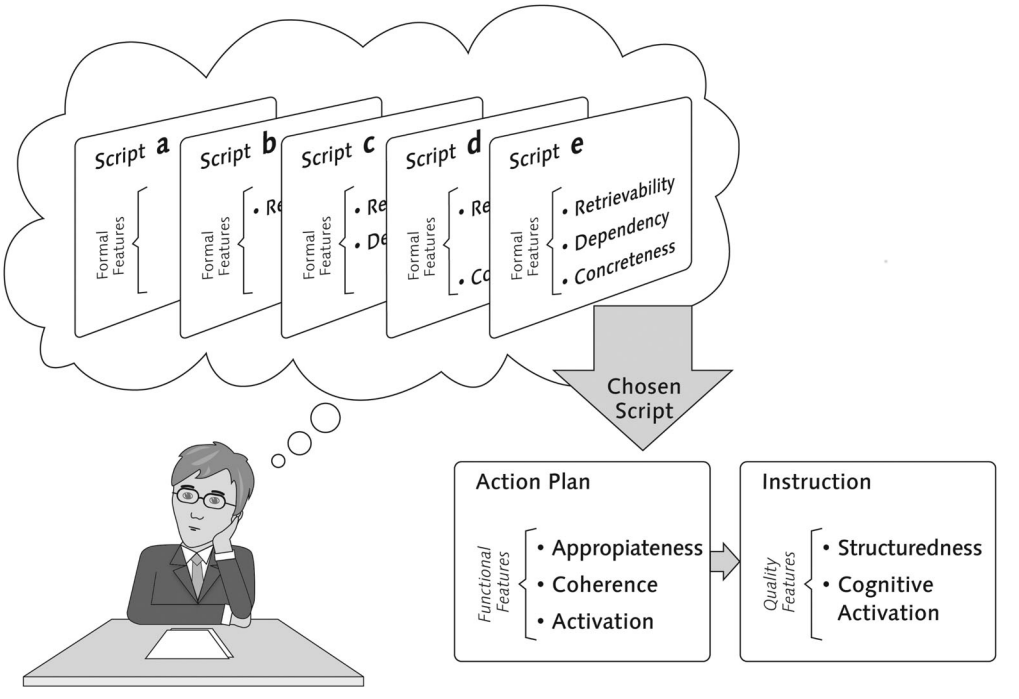

Figure 3. Quality criteria of teaching scripts.

are moderating factors on the influence of his or her TSPK on the quality of teaching scripts. Nonetheless, this assumption has to be tested empirically. In order to do so, we address the following research question in this study: To what extent do teacher's beliefs, motivation and self-regulation moderate the influence of the teacher's TSPK on the quality of teaching scripts?

3. Methods

3.1. Design and sample

According to the Transformation Model of Lesson Planning, it is assumed that teachers' TSPK influences their teaching scripts, moderated by respective teachers' affective dispositions. As TSPK and teaching scripts can be expected to be topic-specific, we examined teachers' TSPK and their teaching scripts for teaching the force concept and Newton's laws in the 9th grade. The data were collected with a quantitative approach using an online-survey. The teachers were asked via email to participate in the online-survey on a voluntary basis. We initially sent an email to 24 teachers who were well known by our research group and had expertise in the field of science education (e.g. mentoring pre-service teacher or experienced teachers). These teachers passed our email to other physics teachers, so we had word of mouth advertising for the survey. We could recruit a total of $n = 49$ physics teachers to participate in the study using this tactic. Every participating teacher was offered a 25 Euro Amazon voucher. This was important because the complex and adaptive online-questionnaire demanded a high compliance of the teachers.

The sample recruited from 7 federal states of Germany consisted of 9 female and 40 male teachers with an average physics teaching experience of 13.5 years.

3.2. Instruments

The teachers were questioned about their TSPK for teaching the force concept and Newton's laws, their beliefs/values, their motivation as well as their self-regulatory skills utilising instruments developed and successfully implemented in previous research studies. The instrument to investigate the participants' teaching scripts, in particular their quality, was newly developed.

3.2.1. Topic-specific professional knowledge

TSPK is assumed to be mentally represented in propositional structures. Therefore, TSPK can be measured by a paper & pencil test in an online version . The TSPK was measured for the force concept and Newton's laws using items of a test developed by Sorge, Kröger, Petersen, and Neumann (2017). The test focuses on measuring the TSPK that novice teachers acquire during the academic part of their teacher training. The underlying model of the TSPK is Magnusson's (1999) conceptualisation, which differentiates between four components: knowledge of students' understanding, instructional strategies, the science curriculum and assessment. Some items query directly canonical knowledge about these components, some indirectly by identifying theory-based action or by choosing correct applications of this knowledge in particular teaching situations. One example of an item which measures TSPK by identifying theory-based action is shown in Figure 4.

The aim was to capture the TSPK of all four components. So, the test consisted of 17 items distributed among these 4 components. All items were multiple choice items with one correct answer. Due to the small number of items and participants we could not construct different scales for each component based on our data structure. But the internal consistency of an overall scale measuring TSPK was estimated by the average item discrepancy $r_{it} = .31$ and Cronbach's $\alpha = .71$. The values indicate adequately good reliabilities, given the small number of items and participants.

3.2.2. Affective dispositions

Affective dispositions were measured using four-point Likert scales. For each disposition, the answer options were 'fully applies', 'largely applies', 'does not apply fully' and 'does not apply at all'. To assess the affective dispositions, we adapted different established scales.

Beliefs/Values: The scale for transmissive beliefs is based on an adaption of a scale of Staub and Stern (2002) rewritten for physics instruction by Seidel, Prenzel, Duit, and Lehrke (2006). The 6-item scale (e.g. 'Teachers should provide detailed procedures for conducting experiments') had an average item discrepancy of $r_{it} = .46$ and an internal consistency of $\alpha = .74$. To assess teachers' values for lesson planning, a 6-item scale for measuring spontaneous lesson planning was adapted (originally from Lipowsky et al., 2009; e.g. 'I think it is important that physics lessons are roughly planned to respond freely to the students'; $r_{it} = .47$; $\alpha = .73$).

Motivation: For measuring enthusiasm, a three-item scale developed by Baumert (2009) was adapted for physics instruction (e.g. 'I enjoy teaching physics'; $r_{it} = .70$; $\alpha = .83$). The six-item scale for measuring self-efficacy focuses on general aspects in

During a physics lesson:

...

Mona: *"Once the ball leaves the shotputters hand, the force is stored in the ball. The larger the force the further the ball flies."*

Mrs. H. *"You are thinking along the right lines. But you can't store force. In this case, physicist speak about energy."*

Mona: *"Thus, the shotputter transmits energy to the ball and this is stored?"*

Mrs. H: *"Exactly, but what happens with the energy afterwards?"*

...

Mrs H. tries to initiate a "Conceptual Change". Which of the following strategies for the initiation of a "Conceptual Change" corresponds to her approach?

A Strategy of confrontation

B Strategy of bridging

C Strategy of reinterpretation

D Strategy of avoiding

Figure 4. Example item for measuring TSPK; theoretically based on a compilation of strategies for initiating a conceptual change presented in 'Physikdidaktik Kompakt' [physik didactics – compact] (Wiesner, Schecker, & Hopf, 2011).

teaching situations (e.g. 'I dare to motivate my students to solve new problems'; $r_{it} = .40$; $\alpha = .67$; originally from Baumert, 2009).

Self-regulation: Self-regulatory skills focus on teachers' ability to focus on tasks of planning and teaching (nine items; e.g. 'If I get distracted, I can quickly return to my task'; $r_{it} = .40$; $\alpha = .73$; Schwarzer & Jerusalem, 1999).

Although the commonly accepted cut-off point of .70 for Cronbach's α is not reached for all of the scales, the values still indicate adequate to good internal consistencies of the scales, given the small number of items and participants (Field, Miles, & Field, 2012). It can be concluded that the tests can be used to reliably measure the assumed amplifiers and filters.

3.2.3. Teaching scripts

We assume that teachers use their TSPK to create lesson plans during lesson planning. The implementation of these lesson plans and teachers' reflection upon them lead to their refinement. With on-going reflection and refinements these lesson plans were mentally stored as teaching scripts teachers can easily retrieve during instruction. Hence, lesson planning is a fundamental process for the development of teaching scripts based on TSPK. To find empirical evidence for our assumption that TSPK influences teaching scripts, we needed a method to capture teaching scripts in a standardised way on a larger sample size coupled with planning processes. Within the theoretical framework of teaching scripts it is assumed that the activation of teaching scripts is stimulated by

the recognition of typical situations (Rumelhart, 1980; Schnotz, 1994). Hence, we developed a new instrument built on planning vignettes which confronted teachers with situations that required them to plan. Three planning vignettes were based upon authentic planning situations, derived from videos of physic lessons from a project that analysed typical instructional patterns for lessons on mechanics (Seidel et al., 2006). All vignettes focus on lesson planning for the introduction into the force concept and Newton's laws ((9th grade), see one planning vignette in Figure 5).

The vignettes were implemented using the online-survey platform (LimeSurvey, 2015), which enabled us to capture teaching scripts via computer. The survey is adaptive in the sense that the respondent can follow different routes of questioning. The flowchart displayed in Figure 6 shows the adaptivity and pathways of questioning. After seeing the planning vignette, the respondents were asked which planning area (content, objective, methods, classroom organisation, tasks, experiments or others) he or she would first take into account when it comes to preparing this specific lesson (See Figure 6, Question 1: closed response format: planning areas as options). The selection of planning areas was based on an analysis of theoretical planning models and results of studies describing teachers' decision-making processes during lesson planning (John, 2006; Peterson, Marx, & Clark, 1978; Taylor, 1970; Yinger, 1980; Zahorik, 1975).

After the respondent decided on the planning area, the respondent was asked if he or she spontaneously could say what he wants to implement in the lesson according to this planning area (Question 2, closed response format: yes or no). With this question, we

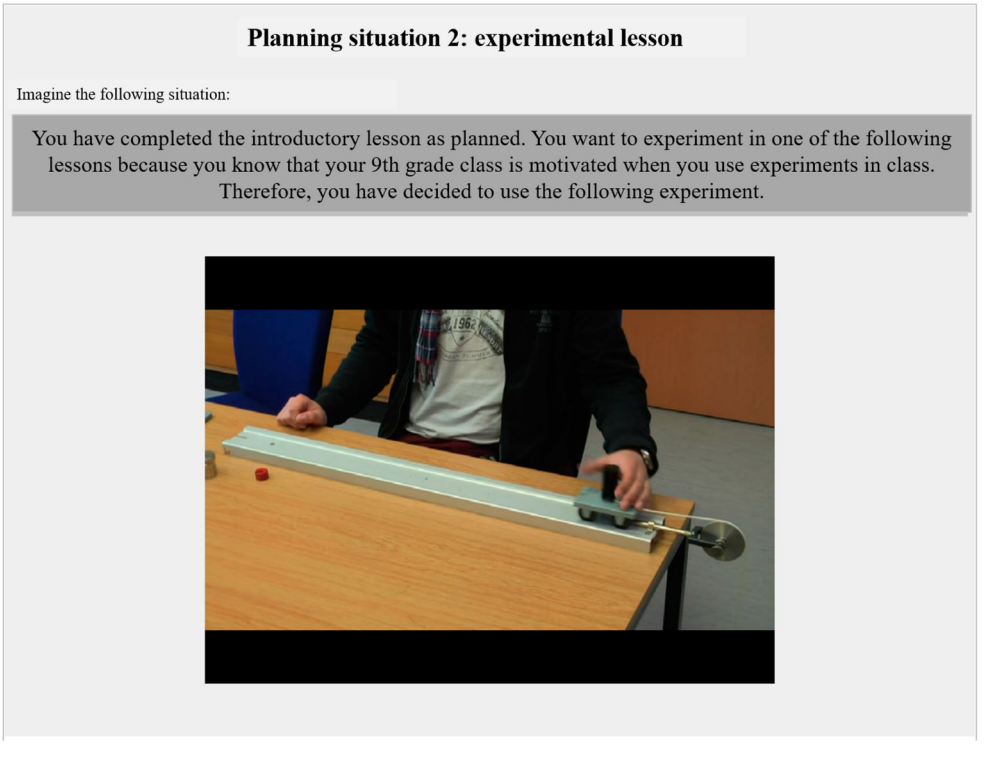

Figure 5. The planning vignette for an experimental lesson.

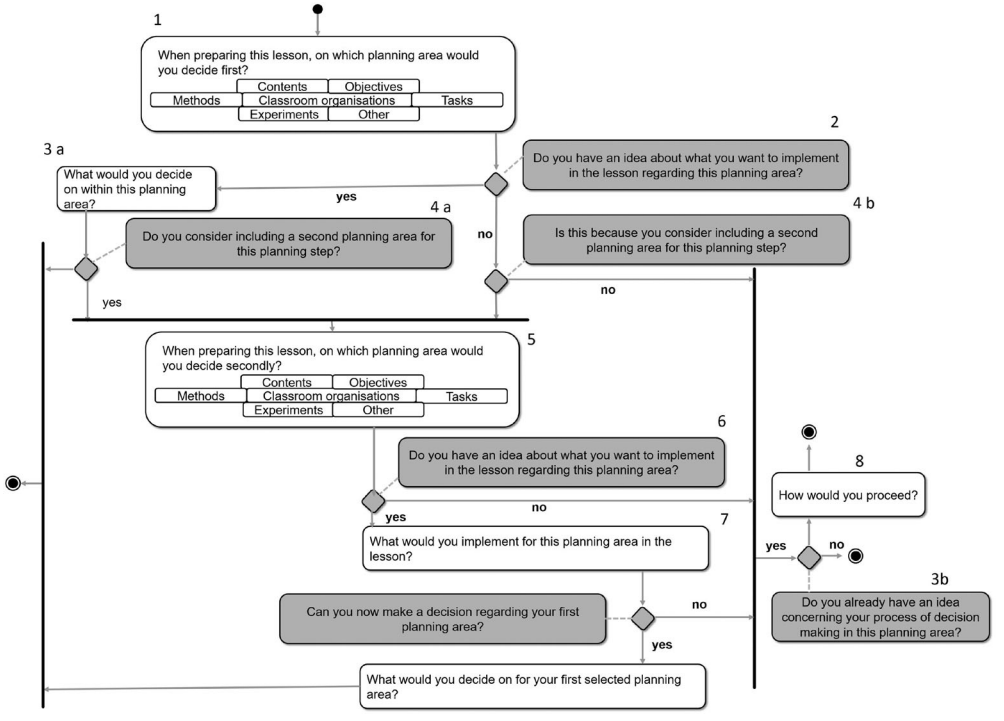

Figure 6. Flowchart of the questionnaire.

could analyse the retrievability of a teaching script. Adaptively, if the respondent answered this question with yes, he or she was asked which content he would want to implement (Question 3a, open response format). If the respondent could not spontaneously answer about what to implement he or she was alternatively asked about how he planned to come to a decision according this planning area (Question 3b open response format). Following both pathways of questions, the respondent also had to specify if he or she would consider a second planning area in their decision (Questions 4a & 4b, closed response format: yes or no). With these questions we can analyse how dependent the decision in one planning area is on another decision in a second planning area (dependency). Afterwards we asked those teachers who considered a second planning area the same questions as for the first planning area. They had to specify in which planning area they wanted to decide secondly (Question 5: closed response format: planning areas as options) and if they already had an idea for this planning area (Question 6: closed response format: options yes or no). Adaptively, if the teacher had an idea, he or she is asked what he or she would want to implement during the lesson according this planning area (Question 7: open response format). If he or she had no idea, he or she is asked about how he or she plans to come to a decision (Question 8: open response format). The third column of Table 1 shows the answer of a teacher who follows one pathway of questions assigned to the questions (Column 1 and 2) and the features of a teaching script we tried to measure with this question (Column 4). In the following we describe how we use the answers for scoring each feature (Column 5).

Table 1. Example of a teaching script.

Question number	Question	Example of a teacher's answer	Measured feature	Score
1	When preparing this lesson, on which planning area would you decide first?	Objectives	–	–
2	Do you have an idea about what you want to implement in the lesson regarding this planning area?	Yes	Retrievability	1[a]
3a	What would you decide on within this planning area?	1. Planning of an experiment for the relationship of force and acceleration. 2. Variation of parameters and appropriate analysis of experiments (here the formula of a = F/m) with respect to measurement inaccuracies'	Concreteness Appropriateness Coherence Activation	2[b] 1[b] 1[b] 2[a]
4a	Do you consider including a second planning area for this planning step?	Yes	Dependency	1[a]
5	When preparing this lesson, on which planning area would you decide secondly?	Classroom organisation	–	–
6	Do you have an idea about what you want to implement in the lesson regarding this planning area?	Yes	–	–
7	What would you implement for this planning area in the lesson?	The materials for the experiment are often available for groups of 5 students, respectively. Therefore, a decision for group work is possible	Concreteness Appropriateness Coherence Activation	2[b] 2[b] 2[b] 2[a]

[a]Overall score of the whole teaching script.
[b]Score of one decision (the overall score for the whole teaching script is the mean value).

The measurement of the quality of teaching scripts that we captured with this instrument is based on the answers we collected with this adaptive questionnaire. However, we had to further analyse the answer with respect to the quality of teaching scripts. We assumed that the quality of teaching scripts determines routines in teaching as well as the potential of teachers to provide high-quality instruction. Based on this assumption we differentiated between formal and functional features of teaching scripts. As described above, formal features measure differences between teaching scripts of experienced and novice teachers. These features are the retrievability of teaching scripts, the dependency of decisions on different planning areas and the concreteness of decisions. In disparity to the formal criteria, the functional criteria are closely related to instructional quality. These features are the appropriateness of decisions to the teaching situation, the coherence of decisions and the possibility of cognitive activation of students during classroom instruction. It is assumed that these features can measure whether a teaching script can lead to high-quality instruction or not.

As shown in Figure 6 and the description above, two different response types were used in our questionnaire: a closed response format and an open response format. To assess the retrievability and the dependency of decisions we used the questions 2 and 4a or 4b with the closed format and the answer options of 'yes' or 'no' (see Table 1). To assess the concreteness, the appropriateness, the coherence and the activation of a teaching script, we used the answer to the questions with the open response format (Questions 3a, 7 and 8). The answers were rated on a scale from 'does not apply' (0 points) over 'partially

applies' (1 point) to 'applies' (2 points) to the feature. Every single answer was rated for the features concreteness, appropriateness and coherence. The mean value of the scores was set as the overall score for the teaching script. For the activation, the retrieved answer was rated according to the potential to cognitively activate students during instruction. As an example, the rating scheme for the capabilities of scripts to cognitively activate students is shown in Table 2 and the rating scores for our example of a teaching script are shown in Table 1 (Column 5).

The objectivity of the rating was checked by double coding 20% of the data set. Due to the ordinal scaled data, weighted Kappa and Spearman's ρ were computed for inter-rater agreement. The values of the inter-rater agreement are shown in Table 3. According to Landis and Koch (1977), values of Kappa above .75 represent excellent agreement and values between .40 and .75 represent fair to good agreement. According to these benchmarks the inter-rater agreement of this study can be judged as good.

In summary, we captured both teaching scripts with the help of our adaptive instrument and measured the quality thereof with the help of a rating scheme and a coding system (see Table 1 for the construction of our generated scores for the quality of a teaching script based on our raw data, represented by an exemplary response structure of a teacher).

The vignette test consists of three different planning vignettes and the teachers were questioned on the teaching scripts several times. Different values, which were generated by different planning vignettes, were combined to one scale for each feature. The values of Cronbach's α of the scales as a measurement of the internal consistency are displayed in Table 3.

The values for Cronbach's α calculated for the indicators of the formal and functional quality of teaching scripts are all higher than .60 in our study. Values of Cronbach's α above .60 indicate an adequate internal consistency of scales with a small number of items (Field et al., 2012). Based on our values of Cronbach's α and due to the small sample size, we can conclude that we objectively and reliably measure the features of the scripts with the developed instrument.

3.3. Data analysis procedures

The administered instruments measuring teachers' TSPK, beliefs/values, motivation and self-regulatory skills as well as the instruments measuring teaching scripts allowed us to capture data in a standardised and efficient way. With these data we were able to analyse influences of experienced teachers' cognitive and affective dispositions on the formal and functional quality of their teaching scripts.

Table 2. Rating scheme for activation.

General description		The response of a teacher is activating, if the decision leads to a cognitively activating instruction. *Indicators* could be that the learners can develop their own ideas, concepts and solutions or that prior knowledge of students is activated during instruction. The lesson is planned to be student-centred.
Subcategories	Apply	The decision of the teacher leads to a cognitively activating instruction
	Partially apply	The decision of the teacher does lead to a student-centred lesson, but the decision allows only little flexibility in terms of the reactions of students.
	Does not apply	The decision does not lead to an open and student-centred lesson. It rather offers the potential, that the lesson is teacher-centred and narrowed.

Table 3. Inter-rater reliability and reliability of scales for the formal and functional features of scripts.

	Interrater-agreement		Reliability of scales		
Feature	Kappa	Spearman's ρ	# Items	r_{it}	Cronbach' α
Retrievability			6	0.50	0.76
Dependency		No rating	6	0.36	0.63
Concreteness	0.64	0.69*	4	0.40	0.62
Appropriateness	0.71	0.72*	4	0.48	0.69
Coherence	0.66	0.73*	6	0.37	0.62
Activation	0.66	0.81*	4	0.48	0.70

*$p < .05$.

We use the PLS-SEM to investigate these influences. This method allows us to study complex multivariate relationships among observed and latent variables (Haenlein & Kaplan, 2004; Hair, Hult, Ringle, & Sarstedt, 2014). The PLS-SEM method is an alternative to the covariance-based SEM (CB-SEM) in case of small sample sizes and non-normally distributed data. PLS-SEM allows a more data-driven exploratory analysis to identify key constructs for maximising the explained variance of estimated variables.

To conduct a PLS-SEM analysis, we first had to specify the measurement models (Hair et al., 2014; see Figure 7). In our analysis, the measurement of teachers' TSPK, their beliefs, motivation, self-regulation and the measurement of formal and functional quality of scripts was carried out by several manifest indicators (e.g. beliefs/values: constructivist beliefs, values for lesson planning, motivation: enthusiasm, self-efficacy). These indicators have to be combined in order to measure the assumed latent factors (e.g. motivation/volition is measured by enthusiasm and self-efficacy). The combination we assumed for our measurement models are seen in Figure 7.

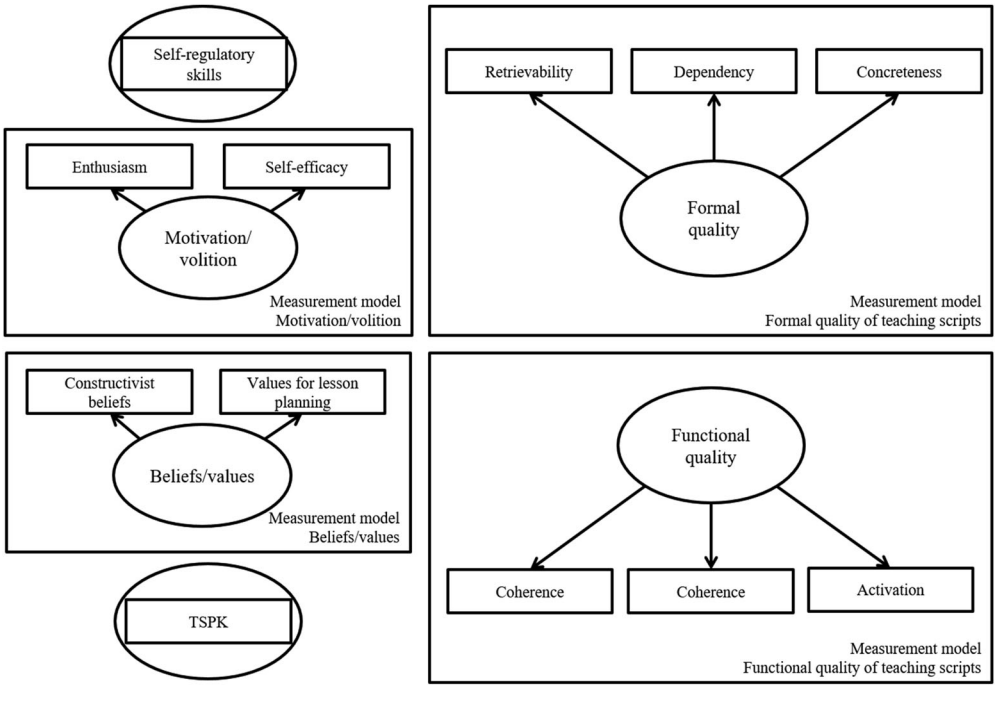

Figure 7. Measurement models.

The quality of the measurement models is typically measured by the composite reliability, the average variance extracted (AVE) and the Fornell–Lacker criterion (Hair et al., 2014). The composite reliability is a criterion for the internal consistency and yields values comparable to Cronbach's α. The AVE is a measure for the composite validity. A value above .50 indicates that the construct explains more than half of the variance of its indicators. In addition, the discriminant validity can be proven with the Fornell–Lacker criterion: The square root of the AVE has to be greater than its highest correlation with any other construct.

The structural model was developed in a second step of the analysis. This model describes the assumed multivariate relationships among the latent variables. In our study we hypothesised that teachers' beliefs and their values, motivation and self-regulation moderate the influence of teachers' TSPK on the formal and functional quality of their teaching scripts. The criteria for the quality and predictive power of the structural model, based on these assumptions, are the coefficient of determination (R^2 value), the value of path coefficients and the effect size f^2. These criteria were interpreted as they are in multiple regressions. Hair et al. (2014) propose that the analysis of moderation effects with the PLS-SEM approach can be conducted in two steps: an optimisation of the quality of the measurement model without the moderation effect and a subsequent analysis of the quality and predictive power of the structural model with the assumed moderation effect. The scales of all indicators were z-standardised and mean replacement for missing values was used, as is advised for PLS-SEM (Hair et al., 2014). The analysis was conducted using the SmartPLS 2.0 software (Ringle, Wende, & Will, 2005).

4. Results

Our aim was to analyse the transformation of TSPK into PCK. Based on our model, we assume that beliefs, motivation and self-regulatory skills moderate the influence of TSPK on personal PCK. The analysis of these types of moderation effects within the PLS-SEM approach is usually conducted in two steps (Hair et al., 2014). Accordingly, we report our findings regarding the analysis of the moderation effect in two steps. First, the underlying structure of the raw data and the quality of the measurement models are presented. In a second step, the results of the analyses of the moderation effects are presented.

4.1. Step 1: Underlying structure of the data and quality of the measurement models

Due to our aim of examining our assumptions on moderation effects we had to analyse multivariate relationships among latent variables. We opted for the PLS-SEM approach to analyse multivariate relationships. This is an alternative to the more popular CB-SEM in case of small sample sizes and non-normally distributed data. In order to decide whether or not PLS-SEM would be better suited for our data structure than CB-SEM, the data were analysed according to the distribution of the manifest indicators. The results show that most of the data for the manifest indicators are not normally distributed (see Table 4).

Based on the non-normality of distributions of the manifest indicators and the small sample size, we decided to use the non-parametric PLS-SEM approach. In comparison to

the CB-SEM it allows a more data-driven procedure to optimise the quality of the measurement models (Hair et al., 2014). We were able to model our latent factors based not only on theory but also on correlations between manifest indicators (see Tables 5 and 6).

Based on our model, we assumed TSPK to be the only factor directly influencing teaching scripts. The correlations show that TSPK is not associated with the other indicators and therefore, indeed, has to be treated as a single factor (see Table 5). The significant correlations between enthusiasm, self-efficacy and self-regulatory skills indicate that these dispositions of a teacher can be combined to one latent factor. This latent factor contains affective dispositions and is therefore called motivation/volition. It is one assumed moderating factor on the influence of teachers TSPK on teaching scripts. Another assumed moderating factor was beliefs/values with the manifest indicators being constructivist beliefs and values of lesson planning. However, these indicators do not correlate, neither among each other nor with other indicators, and had to be treated as single moderating factors.

Possible combinations of manifest indicators to assumed latent factors which represented the quality of teaching scripts (see Table 6) could be deduced from the correlations between all manifest indicators for all quality criteria of teaching scripts. Retrievability, dependency and concreteness are associated. As assumed, they could be combined to measure the formal quality of scripts. The significant correlation between coherence and activation indicate that these aspects are closely related. As a consequence, they could be combined into a single latent factor representing the functional quality of teaching scripts. The feature appropriateness, however, is correlated neither with the features measuring the formal quality nor with the features measuring the functional quality. It seems that appropriateness is not directly associated with the formal or functional quality of teaching scripts.

Based on the correlations, we decided on our latent factors and conducted a first PLS-SEM analysis with all manifest factors to check the quality of the measurement models. It is advised by Hair et al. (2014) to analyse the quality of the measurement models without included interaction-terms for the assumed moderation effect in the first instance. Therefore, we assumed that TSPK, constructivist beliefs, values for lesson planning and motivation/volition equally influence the formal and functional quality of scripts. The results are shown in Figure 8.

Table 4. Descriptive statistics.

Variable	Mean	SD	Min	Max	Shapiro-Wilk Test
TSPK					
TSPK mechanics	.70	.21	.00	1.00	$W = .89$, $p < .01$
Amplifiers and filters					
Constructivist beliefs	2.45	.48	1.57	3.57	$W = .98$, $p = .95$
Values lesson planning	2.70	.39	1.67	3.33	$W = .93$, $p = .10$
Enthusiasm	3.61	.50	2.33	4.00	$W = .78$, $p < .05$
Self-efficacy	3.15	.36	2.67	4.00	$W = .89$, $p < .05$
Self-regulatory skills	3.26	.38	2.56	3.89	$W = .97$, $p = .65$
Features of scripts					
Retrievability	.71	.34	.00	1.00	$W = .79$, $p < .05$
Dependency	.60	.36	.00	1.00	$W = .86$, $p < .05$
Concreteness	1.55	.53	.00	2.00	$W = .80$, $p < .05$
Appropriateness	.28	.40	.00	1.58	$W = .72$, $p < .05$
Coherence	1.57	.49	.50	2.00	$W = .82$, $p < .05$
Activation	.77	.54	.00	2.00	$W = .95$, $p < .05$

Table 5. Correlations between all manifest indicators of teacher TSPK, beliefs/values, motivation and self-regulation.

Assumed latent factor		Manifest indicator	1	2	3	4	5	6	Latent factor based on data structure
TSPK	1	TSPK mechanics	1	−.11	.10	.18	.08	.20	TSPK
Beliefs/values	2	Constructivist beliefs		1	−.19	.11	−.29	.04	Constructivist beliefs
	3	Values LP			1	.19	.05	−.33	Values LP
Motivation	4	Enthusiasm				1	.35	.39*	Motivation/volition
	5	Self-efficacy					1	.65*	
Self-regulation	6	Self-regulatory skills						1	

*$p < .05$.

We first had to check the quality of the measurement models. The correlation between the manifest indicators we presented above merely offered first hints about the internal structure, but only with the actual PLS-SEM analysis were we able to draw conclusions concerning the quality of the measurement model. Typically, an AVE of above .50 and a composite reliability above .60 are required to accept the measurement model. Furthermore, the Fornell–Lacker criterion has to be fulfilled. That is, the square root of the AVE has to be greater than its highest correlation with any other construct.

All quality criteria for the measurement model are acceptable (Table 7). Therefore, the measurement model was accepted as fitting best to the data structure. However, the results also show that constructivist beliefs as well as values for lesson planning have no significant influence on the formal and functional quality (see Figure 8). Therefore, these factors were omitted from the analysis of the moderation effects of teachers' affective dispositions.

4.2. Step 2: Analysis of the moderation effect

In order to answer our research question we had to analyse the moderation effect of motivation/volition on the influence of TSPK on the formal and functional quality of teaching scripts. Therefore, we had to include an interaction-term in the SEM-Model 1. Therefore, we had to include an interaction-term in the SEM-Model 1. The inclusion of interaction-terms had only little effect on the quality of the measurement models, as the quality criteria do not differ significantly between SEM-Models 1 and 2. Therefore, the results of the analysis of the resulting SEM-Model 2 are shown in Figure 9.

The results indicate that we can explain 22% of variance in the formal quality with motivation/volition and TSPK. More specifically, in-service teachers' motivation/volition moderately influences the formal quality of their script with an effect size of $f^2 = .05$. The

Table 6. Correlations between all manifest indicators of the quality of teaching scripts.

Assumed latent factor		Manifest indicator	1	2	3	4	5	6	Latent factors based on data structure
Formal quality	1	Retrievability	1	.42*	.43*	−.02	.05	.10	Formal quality
	2	Dependency		1	.39*	.24	.26	.33	
	3	Concreteness			1	.10	.28	.27	
Functional quality	4	Appropriateness				1	−.17	.28	Functional quality
	5	Coherence					1	.41*	
	6	Activation						1	

*$p < .05$

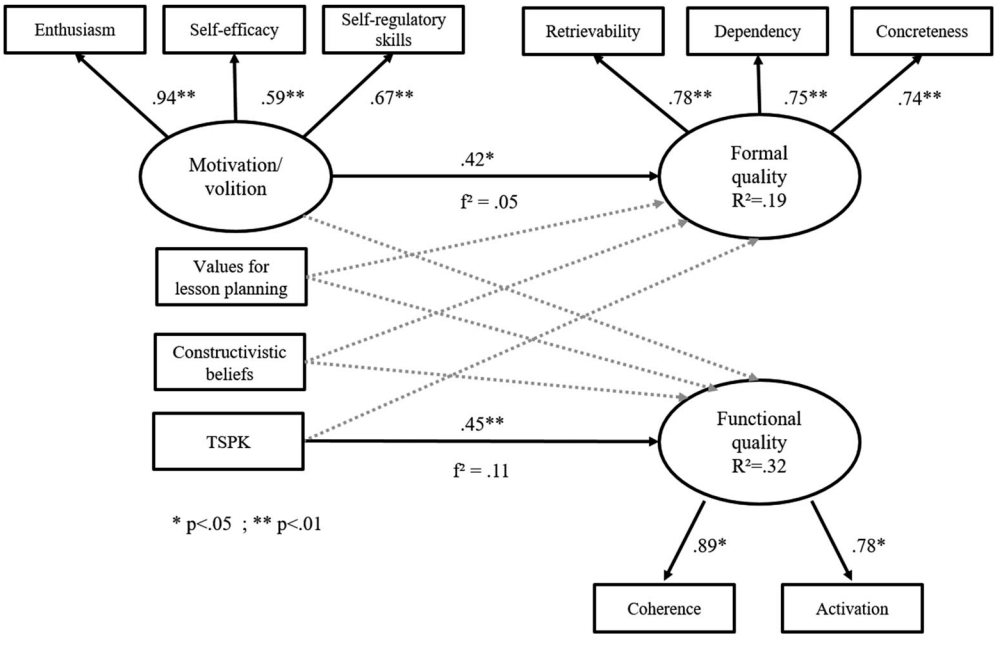

Figure 8. SEM-Model 1: Results of the estimation of direct influences. Solid lines represent significant path and dashed lines represent non-significant paths. Presented are standardised path coefficients**.**
Note: TSPK: topic- specific professional knowledge.

interaction-term of TSPK*motivation/volition has a small influence with $f^2 = .01$. According to the functional quality of teaching scripts, we can explain 26% of the variance with TSPK and the interaction effect of TSPK*motivation/volition. Here, the main influencing factor is not motivation/volition but TSPK. TSPK moderately influences the functional quality ($f^2 = .07$). The interaction effect only has a small influence with $f^2 = .01$. Therefore, we found moderate direct effects of motivation/volition on the formal quality and of TSPK on functional quality. We can also find small moderation effects of motivation/volition on the influence of TSPK on the formal and functional quality of scripts.

5. Discussion

As discussed in Section 2, the teacher professional knowledge and skills model assumes impacts of teachers' TSPK on their personal PCK influenced by amplifiers and filters,

Table 7. Quality criteria of the SEM-Model 1.

				Fornell–Lacker criterion					
	Latent factor	Composite reliability	AVE	1	2	3	4	5	6
1	TSPK	1	1	**1**					
3	Constructivist beliefs	1	1	−.10	**1**				
4	Values for lesson planning	1	1	.09	−.19	**1**			
5	Motivation/volition	.78	.56	.22	.05	.06	**.74**		
6	Formal quality	.80	.57	.11	.00	.09	.43	**.75**	
7	Functional quality	.82	.70	.49	−.18	.29	.15	.25	**.83**

Note: The diagonal represents square roots of AVE of the construct; below the diagonal are correlations

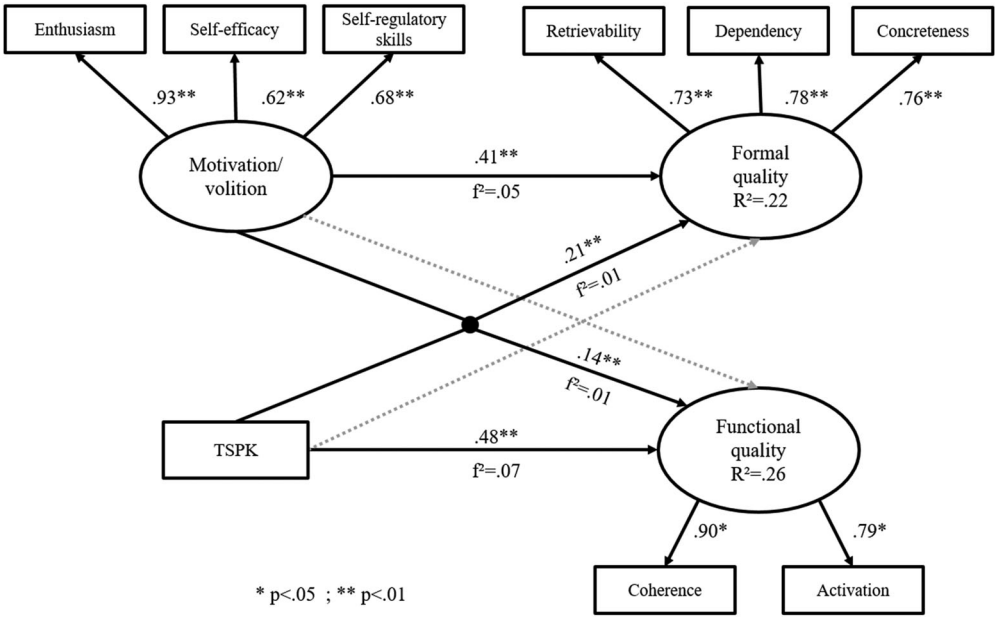

Figure 9. SEM-Model 2: Results of the estimation of moderation effects. Solid lines represent significant path and dashed lines represent non-significant paths. Presented are standardised path coefficients.
Note: TSPK: topic-specific professional knowledge.

such as their beliefs or motivations (Gess-Newsome, 2015). However, the model does not specify how this impact develops. Consequently, we proposed a theoretical model that describes the transformation process from TSPK into personal PCK, mentally represented by teachers' teaching scripts. We assumed that beliefs and values, motivation and self-regulation of teachers were moderating factors on the influence of TSPK on the quality of teaching scripts and aimed at testing these hypotheses with our study.

5.1. Discussion of the results

To validate the assumption that beliefs and values, motivation and self-regulation moderate the influence of TSPK on the quality of teaching scripts, we assessed all of these factors with an online questionnaire thematically adapted to teaching the force concept and Newton's laws in the 9th grade. For the analysis of the non-normally distributed data, we used the PLS-SEM, which allowed us to study the expectedly complex relationships between TSPK and the quality of their teaching scripts within our chosen topic.

In a first step of the analysis, we had to examine whether our assumptions about the structure of the measurement models agreed with the data or not. We assumed it would be necessary to distinguish between the formal and functional features for the analysis of the quality of teaching scripts. Formal quality was measured by estimating the retrievability, dependency and concreteness. These formal and functional features fulfilled the quality criteria for measurement models, so this assumption seems to be appropriate for the data structure (see Table 7). We assumed that the functional quality can be

measured by appropriateness, coherence and activation. Yet, our analysis showed that appropriateness is not associated with the other functional features (see Table 6). Nevertheless, judging by the results estimating the quality of our measurement model, we can conclude that our newly developed instrument can capture the formal and functional quality of teaching scripts. However, appropriateness does not seem to be a functional feature according to our data structure. So, we had to rethink if appropriateness is an aspect of the functional quality of a teaching script. In order to decide this, the measurement of appropriateness should be revised in a first step.

In the second step, we analysed the influence of teachers' TSPK, their beliefs and values, their motivation as well as their self-regulation on the formal and functional quality of their teaching scripts and the interaction effects. We found direct influences on the quality of teaching scripts as well as moderation effects between teachers' TSPK and their motivational and volitional dispositions. Motivational and volitional dispositions influence the formal quality of teaching scripts directly (see Figures 8 and 9). In particular, the formal quality describes how teaching scripts enable teachers to act in a routine way in teaching situations. The results indicate that teachers need motivational and volitional skills to acquire teaching routines (Renkl, 1996). The second identified direct effect shows that TSPK influences the functional quality of teaching scripts (see Figures 8 and 9). Specifically, this result supports the assumption that personal PCK – represented in the Transformation Model of Lesson Planning as teaching scripts – is informed by TSPK (cp. TSPK & S Model and the Transformation Model of Lesson Planning).

Within our framework, we additionally assumed that the transformation of TSPK into teaching scripts is moderated by motivational and volitional aspects. Our results confirm the assumption of this moderation effect (see Figure 9). The influence of TSPK on the formal and functional quality of scripts is higher if the teachers additionally have a high motivation and high self-regulatory skills. Based on the TPK&S Model (Gess-Newsome, 2015) and the more detailed description of the transformation processes using the Transformation Model of Lesson Planning, we were able to identify assumed influences of TSPK on personal PCK measured by teaching scripts. Additionally, this study shows an indication of moderation effects between motivational and volitional dispositions and the TSPK on the quality of teaching scripts. This is another empirical hint for the validity of the Transformation Model of Lesson Planning and the TPK&S Model for teaching the force concept and Newton's laws in the 9th grade.

5.2. Conclusion and implications

With the study presented here, we intended to investigate to what extent experienced teachers' TSPK influences the formal and functional quality of teaching scripts, based on the well-founded theoretical TPK&S Model and the Transformation Model of Lesson Planning. The results suggest that the formal and functional quality of teaching scripts is informed by TSPK— a core assumption of both theoretical models. The results also indicate that it is not enough for teachers to develop a large topic-specific theoretical knowledge base about good teaching in their subject. They also have to be motivated to transform this theoretical knowledge into teaching scripts and be able to self-regulate during the complex process of planning, reflection and adaption of plans. Therefore, these amplifiers and filters, as they called in the TPK&S Model, have to be seriously

taken into account as moderating factors for the influence of TSPK on personal PCK in future research studies.

In all different conceptualisation of PCK, one core assumption is that relevant content knowledge is a prerequisite for teachers' PCK (Cochran et al., 1993; Grossman, 1990; Hashweh, 2005; Loughran et al., 2012; Magnusson et al., 1999; Park & Oliver, 2008). From the vantage point of the Transformation Model of Lesson Planning, this means content knowledge indirectly influences the quality of teaching scripts mediated by TSPK. However, we did not capture the content knowledge of our participating teachers. Therefore, we could not analyse if content knowledge is a prerequisite for TSPK and teaching scripts. Hence, we could not draw any conclusions for educational foci in the learning process of student teachers concerning the amount of acquisition of content knowledge or TSPK. Our instrument for measuring TSPK was based on a broad conceptualisation with four components: It includes knowledge of students' understanding, instructional strategies, science curriculum and assessment (Differentiation of components basing on Magnusson et al., 1999). We could verify the influence of TSPK on the quality of teaching scripts based on this broad conceptualisation within the topic of force and Newton's laws in the 9th grade. Moreover, we were also interested in analysing the differences between the influences of each single component of TSPK on the quality of teaching scripts in our analysis. Due to our small sample size and the small number of items we used to capture the TSPK, we were not able to identify them. Future studies here can aid the development of teacher training programmes and supply suggestions regarding outcomes for teaching scripts and instructional quality. Another limitation of our investigations is that it stops one step short of the actual practice in that it investigates teaching scripts which admittedly evolve from practice but are still virtual products in themselves. Direct evidence from actual practice is still necessary because the teaching scripts still provide only virtual knowledge of actual practice. Further research is needed about how TSPK is implemented in real classroom settings, how it successfully evolves in teaching and how it relates to the learning processes of students.

The Transformation Model of Lesson Planning describes a long-term process for transformation of TSPK into teaching scripts as part of personal PCK. It is assumed that reflecting on the results of a lesson feed back into the quality of teaching scripts. The reflection – fostered by direct feedback or not – could create loops that are a key process for the progression of teaching scripts. This might enhance teachers' ability to plan for better practice and to use their practice to develop better planning. It would be helpful to investigate if and how feedback fosters this loop so the teacher shows a higher quality of teaching scripts and high-quality instruction in the classroom. But our study design with its single measurement of teachers' dispositions as well as the formal and functional quality of their teaching scripts does not allow inferences to be drawn about developmental trajectories and their influencing factors. Hence, more research is necessary to identify developmental trajectories. However, the developed instrument already has the potential to measure the progression of formal and functional quality of teaching scripts in the course of teachers' professional development (Stender, 2014).

We can already give science educators some preliminary guidelines based on our results despite these limitations of our study: teachers' TSPK, their motivation and self-regulatory skills are basic dispositions which must be reinforced equally during teacher preparation programmes. Additionally, pre-service teachers must be led during lesson planning and

reflection of the results of their lesson planning to develop high-quality teaching scripts. Since routine and the formal features develop over time, it mainly seems wise to support the development of functional features. Due to the influences of TSPK on the functional features it seems promising to focus on supporting transformation processes of TSPK into teaching scripts. This can be realised by cooperative reflection processes of lesson plans or the results of the implementation of these lesson plans through the lens of criteria for instructional quality.

In conclusion, we want to highlight that the differentiation between TSPK and teaching scripts as part of the personal PCK – as contemplated in the TPK&S Model and in the Transformation Model of Lesson Planning – offers a fruitful agenda for studying teachers' professional knowledge base and their developmental processes.

Disclosure statement

No potential conflict of interest was reported by the authors.

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