

## **Fostering pre-service teachers' situation-specific technological pedagogical knowledge – Does learning by mapping and learning from worked examples help?**

In order to exploit the potentials of digital technology in classrooms, it is necessary to enhance future teachers' situation-specific Technological Pedagogical Knowledge (TPK) as manifested in their professional vision (i.e., their noticing and knowledge-based reasoning of technology-enhanced classroom situations). To this end, we differentiate between formal quality (whether pre-service teachers display reasoning steps related to professional vision) and content quality (whether pre-service teachers make adequate use of scientific knowledge) of pre-service teachers' reasoning about technology-enhanced teaching. Based on empirical findings, we hypothesized that learning by mapping would facilitate the content quality and learning from worked examples would enhance both formal and content quality of pre-service teachers' TPK-related professional vision. We tested these hypotheses with a sample of 252 pre-service teachers who first either read or mapped scientific texts and then either analyzed authentic technology-enhanced classroom cases or received worked examples on how to do so. Results from structural equation modeling demonstrated a positive association of learning with worked examples and content quality, but no relation to formal quality. Learning by mapping even showed rather negative associations with content quality. However, the quality of maps partly functioned as a significant predictor. Possible reasons and consequences are discussed.

**Keywords:** Technological Pedagogical and Content Knowledge (TPACK), professional vision, mapping, worked examples, pre-service teachers

## 1. Introduction

Digital technologies in terms of “technology-based programs or applications that help deliver learning material and support learning processes” (Cheung & Slavin, 2013, p. 90) are thought to hold particular potentials for student learning (Bower et al., 2014; Garrison & Kanuka, 2004; Sandholtz et al., 1997). However, teachers’ technology-related teaching skills, as outlined in the Technological Pedagogical and Content Knowledge (TPACK) framework (Koehler & Mishra, 2008; Mishra & Koehler, 2006), play a significant role in the effective use of digital technologies’ potentials in future classrooms.

While much is known about teachers’ TPACK as manifested in their knowledge, much less is known about teachers’ TPACK as manifested in their situation-specific skills (Chai et al., 2016; Voogt et al., 2013; Willermark, 2018). This seems to be particular true for research on teachers’ reasoning about technology-enhanced teaching which has also been characterized by a lack of theoretical foundations (Harris et al., 2017). Thus, research on professional vision concerned with teachers’ noticing and knowledge-based reasoning in in the context of video-based professional development and pre-service teacher education might be of help to further conceptualize this type of reasoning.

In this regard, the quality of teachers’ professional vision has been investigated from both a formal (i.e., whether or not teachers perform adequate reasoning processes; van Es & Sherin, 2002) and a content perspective (i.e., whether or not teachers make adequate use of scientific knowledge during reasoning; Seidel & Stürmer, 2014). Results in TPACK research indicate that pre-service teachers demonstrate a rather low formal and content quality of professional vision when reasoning about technology-enhanced teaching situations (Greenhow et al., 2008).

As a consequence, in this study we were particularly concerned with possible ways to facilitate the formal and content quality of pre-service teachers' TPACK-related professional vision (TPACK-PV). In that respect, research on teachers' professional vision points to learning with authentic classroom cases as a promising learning opportunity (Sherin, 2004; van Es et al., 2014). Yet, it might be necessary to further support pre-service teachers in order to make better use of these learning opportunities (Kirschner et al., 2006). Learning by mapping scientific texts, an approach that affords students to visually structure and link information (Fiorella & Mayer, 2016), might help pre-service teachers to make adequate use of scientific knowledge to reason about technology-enhanced teaching (content quality). Learning from worked examples, an approach that provides learners with a step-wise solution to a problem (Renkl, 2014), is assumed to support pre-service teachers both in the adequate use of reasoning steps (formal quality) and use of scientific knowledge (content quality). To investigate these assumptions, we looked into the effects of learning by mapping (Fiorella & Mayer, 2015) on the content quality and learning from worked examples (Renkl, 2014) on the formal and content quality of pre-service teachers' TPK-PV in the context of a case-based learning environment. We decided not to include CK and its intersections (PCK, TCK & TPACK) in this study, as we aimed at a better understanding of the application of general evidence-based teaching and learning principles in the context of technology-enhanced teaching. In doing so, we were able to make more general assertions about the effects of learning by mapping and from worked examples on pre-service teachers' knowledge acquisition independent of content-related factors. However, theoretical considerations and empirical results presented in this article are not limited to TPK, but are based on all facets of TPACK.

In the remainder of this article, we first describe the TPACK framework with its knowledge facets and highlight shortcomings in TPACK research that illustrate the need for conceptualizing TPACK from a perspective of professional vision (2.1). In the following subsection (2.2), we outline the concept of professional vision and introduce a differentiation between its content and formal quality. Based on the particularly sobering results for pre-service teachers, section 2.3 introduces learning by mapping and from worked examples as ways to foster the content and formal quality of pre-service teachers' TPACK-PV. After that, we present our hypotheses and our empirical study.

## **2. Theoretical background**

### **2.1. Technology and the importance of teachers' technological pedagogical and content knowledge**

Digital technologies have entered the stage of education not just since Covid-19, but for quite some time now. They are often believed to be enablers and facilitators for high-quality teaching and learning processes (Bower et al., 2014; Garrison & Kanuka, 2004; Sandholtz et al., 1997). However, meta-analyses consistently show that the average effects of technology on student learning are rather small (Schmid et al., 2014; Tamim et al., 2011). Still, the high heterogeneity of effects identified in these meta-analyses indicates that the effects of technology are moderated by further variables. One of these moderator variables seems to be the manner in which teachers implement technology in classroom (Chien et al., 2016; Hunsu et al., 2016; Schmid et al., 2014; Tamim et al., 2011). Hence, there is a need for teachers to acquire relevant technology-related teaching knowledge to better understand which and how technology suits best in which situation.

A prominent theoretical model that defines this kind of knowledge is the TPACK model proposed by Koehler and Mishra (Koehler & Mishra, 2008; Mishra & Koehler, 2006). According to this model, teachers not only need to have technological knowledge to effectively use digital technologies in classroom, but also pedagogical knowledge, content knowledge and pedagogical content knowledge (Shulman, 1986). Beyond these knowledge components, they require intersecting knowledge in the form of technological content knowledge (TCK), technological pedagogical knowledge (TPK) and technological pedagogical content knowledge (TPACK). TCK is described as knowledge about how technology and content influence each other, that is knowledge about how technology might enable certain, but simultaneously constrain other forms of content representation. TPK refers to knowledge about how technology and pedagogy relate to each other, meaning how technology can afford certain forms of teaching and learning and how it might constrain other forms of teaching and learning. Finally, TPACK is understood as situated, flexible combination of content, pedagogical and technological knowledge that teachers activate dependent on the teaching context.

The TPACK framework has gained exceptional recognition both among researchers and teachers (Herring et al., 2016). Yet, there appear to be different concepts on what it actually means to “have” TPACK. On one end of the spectrum, TPACK is studied as knowledge (Cheng & Xie, 2018; Jang & Tsai, 2013), on the other end, it is investigated as competence (Kafyulilo et al., 2015). While “TPACK as knowledge refers to something that the teachers possesses, such as concepts, rules or procedures”, TPACK as competence refers to the observable behavior in actual teaching situations (Willermark, 2018, p. 318).

TPACK as knowledge has gained considerably more attention than TPACK as competence in related research. The few studies that investigated TPACK as situation-

specific skills in between the two ends have mostly focused on how teachers *plan* technology use in classrooms (Willermark, 2018). However, other important situation-specific skills such as the *reasoning* about technology-enhanced classroom situations have seldomly found their way into TPACK research and might therefore still be “under-theorised in TPACK scholarship” (Harris et al., 2017). Thus, research on professional vision that conceptualizes teachers’ professional reasoning processes based on findings on teacher expertise might help to further conceptualize teachers’ situation-specific TPACK in terms of their reasoning.

## **2.2. Conceptualizing teachers’ TPACK from a professional vision perspective**

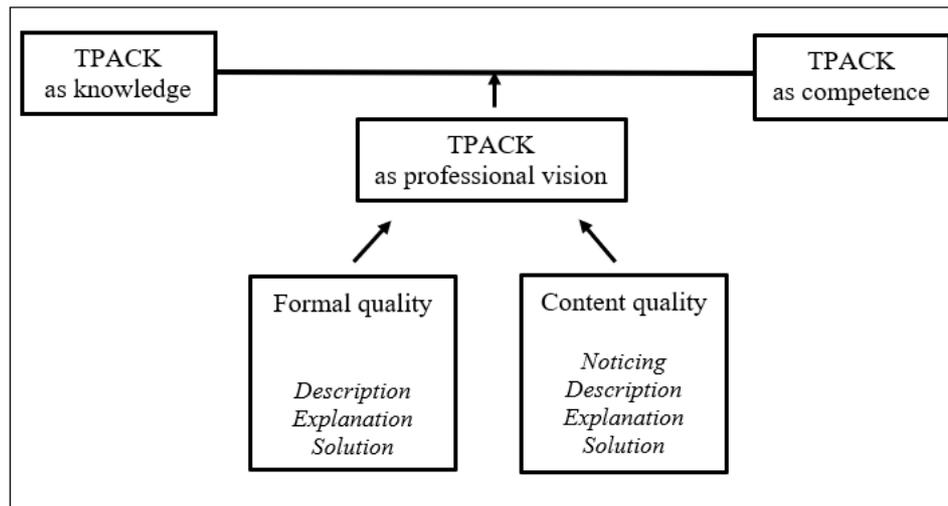
Research on professional vision has mainly been established in the field of video-based professional development of teachers and pre-service teacher education with a strong emphasis on results from research on teacher expertise (Berliner, 2001; Borko & Livingston, 1989; Carter et al., 1988). Findings show that expert teachers are better able than novice teachers to describe classroom situations, detect specific classroom-based activity patterns, develop hypotheses and explanations of how different classroom situations are linked and present solution strategies (Carter et al., 1988). These differences are explained by expert teachers’ more elaborate, complexity-reducing cognitive schemata acquired by means of their teaching experience and their pedagogical content knowledge. Thus, most conceptualizations emphasize two components of professional vision: noticing and knowledge-based reasoning (König et al., 2014; Sherin et al., 2011). *Noticing* refers to the ability to detect relevant events in classroom (Seidel & Stürmer, 2014; van Es & Sherin, 2002), while *knowledge-based reasoning* is understood as the ability to reflect on the relevant events based on one’s own knowledge (Sherin, 2007). Knowledge-based reasoning is often subdivided in (a)

the description (or evaluation) of the relevant events, (b) the explanation (and prediction) of effects and (c) the generation of a solution by elaborating on alternative teacher actions (Kersting et al., 2010; Santagata & Guarino, 2011; Seidel & Stürmer, 2014; van Es & Sherin, 2002). However, in line with evidence suggesting that pre- and in-service teachers mostly only describe events without any form of guidance (Seidel & Prenzel, 2007; Stürmer, Seidel, & Kunina-Habenicht, 2015; van Es & Sherin, 2002, 2008), the latter two sub-processes appear to be more difficult to execute (Seidel & Stürmer, 2014) and thus represent the central quality indicators of professional vision (van Es, 2011; van Es & Sherin, 2002).

While one focus of professional vision models is placed on the *formal quality* of professional vision by measuring which and how well teachers enact the outlined knowledge-based reasoning components or sub-components (Sherin & van Es, 2009; van Es & Sherin, 2008), another is placed on the *content quality* by measuring the degree to which relevant aspects are noticed (see Sherin & van Es, 2009; van Es & Sherin, 2008) and by measuring the adequate application of scientific knowledge when performing knowledge-based reasoning components (see Gold & Holodynski, 2017; Meschede et al., 2017; Stürmer & Seidel, 2015). We propose to take the formal quality as well as the content quality into account when measuring teachers' TPACK as manifested in their professional vision (see Figure 1).

### **Figure 1**

*TPACK as professional vision on the spectrum between TPACK as knowledge and TPACK as competence*



*Note.* Adapted from Willermark (2018).

With regard to the *content quality* of teachers' TPACK-PV, numerous studies have shown that teachers generally make little use of scientific knowledge in their teaching (Bergner, 2018; Hagger et al., 2008; Nelson et al., 2017). This appears to not only be true for teaching in general, but also applies to technology-enhanced teaching (Sailer et al., 2017). Besides personal beliefs, attitudes and organizational conditions, one reason seems to be the lack of knowledge about how to adequately use scientific knowledge (Lysenko et al., 2014). Empirical evidence suggests that in particular pre-service teachers have difficulties to adequately use certain knowledge facets (PK/TPACK) in order to explain events and to develop alternative strategies (König & Kramer, 2016; Kramarski & Michalsky, 2009; Meschede et al., 2017; Seidel & Prenzel, 2007).

Much less is known with regard to the *formal quality* of teachers TPACK-PV. In the field of professional vision, van Es and Sherin (Sherin & van Es, 2009; van Es & Sherin, 2002, 2008) as well as others (Santagata & Angelici, 2010; Yeh & Santagata, 2015) found that pre-service as well as in-service teachers tend to focus on the description and evaluation instead of the explanation of events if they do not receive

any form of guidance. Similar observations were made outside of the field of professional vision. For example, in a study of Csanadi et al. (2020), pre-service teachers rarely generated any explanations of problems that occurred in a fictitious classroom case, but were more likely to generate solutions for problems. Yet, research on the formal quality of teachers' TPACK-PV seems to be very scarce to date.

### **2.3. Fostering pre-service teachers' TPACK-PV**

Results on in- and pre-service teachers' professional vision and TPACK point to an obvious need to facilitate their TPACK-PV. We argue that to acquire TPACK-PV, learning with authentic classroom cases is likely to be beneficial: They illustrate the complexity of classroom teaching, yet without the necessity to act immediately (Sherin, 2004; van Es et al., 2014). Reasoning about such cases may enable pre-service teachers to apply their knowledge, prompt them to generate predictions and explanations and provides the opportunity for continuous learning by reflecting former (case) experiences (Kolodner et al., 2003).

Such cases may come in different formats. Most research in the domain of professional vision makes use of video cases (König et al., 2014; Meschede et al., 2017; Sherin & van Es, 2009; Stürmer & Seidel, 2015). However, written cases have been used as well, at times even documenting certain advantages over the use of video cases: While Kramer et al. (2017) could not find any differences in pre-service teachers' development of professional vision dependent on the type of material presentation (written or video-based), Syring et al. (2016) reported that pre-service teachers stated less cognitive load when working with written compared to video cases. Thus, at least for pre-service teachers, the use of written cases seems to hold certain promises in order to help them develop TPACK-PV.

Still, in order to use the potentials of learning with authentic cases, further instructional guidance is needed (Kirschner et al., 2006) that fosters the content and form quality of pre-service teachers' TPACK-PV. Yet, experimentally-based results on the effects of selected instructional elements that are investigated independent of complete long-term training approaches are still lacking in research on TPACK and professional vision (Gold et al., 2013; Janssen & Lazonder, 2016; Stürmer et al., 2016).

However, individual instructional elements might already turn out to be effective in enhancing pre-service teachers' TPACK-PV. For example, learning by mapping as a generative learning strategy (Fiorella & Mayer, 2016) has been shown to support learners in their acquisition of knowledge from texts (Ponce & Mayer, 2014). Thus, this type of instructional element might help pre-service teachers to more easily represent scientific knowledge cognitively and therefore to more adequately apply it to technology-enhanced teaching situations. In the context of evidence-based reasoning, first evidence from Klopp and Stark (2018) indicates that learning from worked examples might enhance pre-service teachers' knowledge about relevant processes (form quality) and the adequate use of scientific knowledge (content quality) when reasoning about technology-enhanced teaching situations. We therefore decided to implement and investigate the effectiveness of these two instructional approaches in the context of TPACK-PV development.

### ***2.3.1. Learning by mapping as a means to foster content quality***

In order to guarantee a high content quality of TPACK-PV, research illustrates the crucial role of pre-service teachers' PK (König et al., 2014; König & Kramer, 2016; Stürmer, Könings, & Seidel, 2015). Thus, pre-service teachers should be supported in their development of a firm conceptual knowledge base about relevant scientific knowledge before actually studying classroom cases (Seidel et al., 2013). To achieve

this, one promising approach is learning by mapping. This includes a range of techniques in which learners create a configuration of words that are spatially linked to each other based on a text (Fiorella & Mayer, 2015). For example, pre-service teachers might be asked to map the content of one or several scientific texts on technology-enhanced teaching before reasoning about a case.

Learning by mapping is believed to not only afford students to select relevant information to be used as nodes, but also to structure links in a consistent way and to relate the learning material with prior knowledge in order to create a meaningful overall structure (Fiorella & Mayer, 2016). Single studies as well as a review and a meta-analysis confirm the positive effect of learning by mapping compared to other conditions (Fiorella & Mayer, 2015; Ponce & Mayer, 2014; Schroeder et al., 2018). For example, Ponce and Mayer (2014) found that students who created a graphic organizer of a text on different types of steamboats outperformed students who only took notes as well as students who only read the text in a consecutive knowledge test.

There are different theoretical approaches such as the Interactive Constructive Active Passive framework (ICAP; Chi, 2009; Chi & Wylie, 2014) or the Select-Organize-Integrate framework (SOI; Mayer, 2014) that offer explanations for the positive effects of mapping. For example, in the ICAP framework of Chi and colleagues (Chi, 2009; Chi et al., 2018; Chi & Wylie, 2014) learning by mapping is conceptualized as an overt constructive learning activity as it involves the generation of knowledge products that go beyond the initially provided learning material. At the cognitive level, overt constructive learning activities are assumed to afford the creation of new knowledge by inference. Thus, the ICAP framework postulates that an engagement in a constructive mode compared to an engagement in a passive (e.g., reading, listening) or

active mode (e.g., underlining, copying) should result in better learning outcomes, as it involves more high-level cognitive processes than the latter.

However, it is possible that learners do not generally benefit from learning by mapping. For example, in a study with seven-graders Scheiter et al. (2017) showed that the quality of visualizations that students produced on the basis of a text on the greenhouse effect was positively associated with students' consequent learning outcomes, referred to as prognostic drawing effect (Schwamborn et al., 2010). Thus, the positive effects of mapping only seem to materialize when the maps learners create are at a high-quality level.

### ***2.3.1. Learning from worked examples as a means to foster form and content quality***

In research on professional vision, prompting measures have been demonstrated to be successful in facilitating the form quality of pre-service teachers' and in-service teachers' professional vision (Santagata & Angelici, 2010; Santagata & Guarino, 2011; van Es & Sherin, 2002). For example, Santagata and Guarino (2011) found pre-service teachers to improve the formal quality of explanation and solution when analyzing classroom videos after they were scaffolded in their video analysis by means of questions prompting them to perform relevant reasoning activities.

However, results of Wekerle and Kollar (2019) indicate that prompting approaches might need to be enhanced by more elaborated forms of guidance that not only facilitate the form quality but also the content quality of pre-service teachers' TPACK-PV. One prominent approach in this regard constitutes worked examples (Atkinson et al., 2000; Renkl, 2014; Sweller et al., 1998). They consist of a problem statement, solution steps and a (correct) solution. By studying worked examples, learners ideally identify the domain principles relevant to problem solving. By this

means, they support learners' initial skill acquisition (Renkl, 2014). The value of worked examples has been demonstrated in numerous studies in different domains (e.g. physics: van Gog et al., 2006; design: Rourke & Sweller, 2009), as illustrated in the positive effect on students' learning outcome determined in a meta-analysis by Crissman (2006). In addition, in the context of evidence-based reasoning, Klopp and Stark (2018) found that studying worked examples compared to studying non-relevant texts increased pre-service teachers' knowledge about the formal quality and the quality of pre-service teachers' explanations in terms of content quality.

The positive effect of studying worked examples as compared to having students solve problems early-on by themselves is most often explained by Cognitive Load Theory (CLT; Sweller et al., 1998; Sweller et al., 2019). CLT is based on the central assumption that the processing of information while learning is determined by the restricted capacity of working memory. The theory differentiates between three types of cognitive load that influence the capacity of the working memory: intrinsic, germane and extraneous load. Intrinsic load refers to the load induced by the complexity of the information, extraneous load to the load induced by the kind of (often unfavorable) presentation of information and germane load refers to the function of redistributing extraneous to intrinsic load (Sweller et al., 2019). While conventional problem solving affords the use of mean-ends-analysis that usually causes high levels of extraneous load, worked examples are assumed to help learners infer abstract solution strategies and accordingly encourage generative activities (germane load) resulting in better knowledge transfer (Sweller et al., 1998; Sweller et al., 2019).

One crucial aspect that moderates the effect of worked examples is learners' self-explanation of the solution steps (Renkl, 2014), as demonstrated by Hilbert and Renkl (2009). In two studies, they found students who received worked examples on

how to apply a new learning strategy to outperform students who solely applied the learning strategy in consecutive knowledge tests, but only when they additionally received self-explanation prompts. These self-explanation prompts were provided in the form of questions that asked students to identify the learning strategy phase illustrated in the respective worked example and explain reasons for the identification. Thus, in order to enhance pre-service teachers' adequate engagement with worked examples, adding self-explanation prompts to worked examples seems to be promising (Schworm & Renkl, 2007). Overall, the implementation of worked examples might serve as an appropriate means to enhance the formal and the content quality of pre-service teachers' TPACK-PV and its different facets.

### **3. Overview of the study and hypotheses**

In this study, we investigated the effects of learning by mapping on the content quality and the effects of worked examples on the formal and content quality of pre-service teachers' TPK-PV in a written case-based learning environment. We decided to focus on TPK-PV, not TPACK-PV, in order to make more general, content-independent assertions about the effects of learning by mapping and from worked examples.

Students first read texts about evidence-based theories focused on PK (reading) or were additionally instructed to create a map on the text content (mapping). Then, they worked with written cases of classroom lessons that included technology-enhanced teacher and student actions without referring to any teaching subject (TPK-PV). They either received worked examples on how to reason about these cases and were prompted to self-explain them (worked examples), or were asked to reason about these cases without further instruction (problem solving).

### **3.1. H1: Effects of mapping and quality of maps on PK and content quality of TPK-PV**

First, we were interested in the degree to which mapping compared to reading would affect PK and the content quality of pre-service teachers' TPK-PV. In addition, we aimed to find out to what extent the quality of pre-service teachers' maps would be associated with pre-service teachers' PK and the content quality of pre-service teachers' TPK. We set up the following hypotheses:

(H1a) Learning by mapping results in higher PK and content quality than mere reading.

(H1b) The quality of maps is positively associated with PK and content quality.

Hypothesis 1a is based on the generation effect outlined in the ICAP-framework (Chi & Wylie, 2014) and the SOI-framework (Mayer, 2014) as well as on empirical findings (Ponce & Mayer, 2014; Schroeder et al., 2018) illustrating positive effects of learning by mapping on learning outcome. Hypothesis 1b based on the prognostic drawing effect (Scheiter et al., 2017; Schmeck et al., 2014; Schwamborn et al., 2010) that hints at the quality of visualizations as an important factor to influence learning outcome positively.

### **3.2. H2: Effects of worked examples on formal and content quality of TPK-PV**

Second, we sought to assess in what way learning from worked examples would affect the formal and content quality of pre-service teachers' TPK compared to problem solving. We set up the following two hypotheses:

(H2a) Learning from worked examples results in a higher formal quality than problem solving.

(H2b) Learning from worked examples results in a higher content quality than problem solving.

The two hypotheses were based on research on the worked example effect (Sweller et al., 1998; Sweller et al., 2019) and on results of Klopp and Stark (2018) that pointed to the positive effects of learning from worked examples on formal and content quality.

## **4. Method**

### **4.1. Participants**

252 pre-service teachers from a German university voluntarily participated in the study in the context of an advanced psychology lecture. The study took place in two waves, i.e. in winter term 2018/2019 and in summer term 2019. Pre-service teachers were predominantly female (74%), around 22 years old ( $M = 22.23$ ,  $SD = 1.55$ ) and on average in their 4<sup>th</sup> to 5<sup>th</sup> semester ( $M = 4.62$ ,  $SD = 1.55$ ). Around half of the participants studied to become high school teachers (53.6%), the remaining pre-service teachers studied to become elementary school teachers (46.4%). Participants' average prior grade in basic Psychology lectures was a 2 (good,  $M = 2.17$ ,  $SD = 0.71$ ) on a theoretical range from 1 (very good) to 5 (poor). In terms of practical experiences, pre-service teachers had completed around three internships ( $M = 2.78$ ,  $SD = 1.17$ ) and stated to use digital technologies on average four hours per day ( $M = 4.00$ ,  $SD = 2.14$ ).

### **4.2. Design**

We investigated the two between-subject factors mapping (reading vs. mapping) and worked examples (problem solving vs. worked examples) independent from each other as main effects in a 2 x 2 between-subjects design. We did not expect an interaction effect of the factors to occur as, so far, there seem to be no theoretical considerations or empirical findings that would suggest treatment interactions. Participants were

randomly assigned to one of the following four conditions: reading + problem solving (N = 59), reading + worked examples (N = 63), mapping + problem solving (N = 62), reading + worked examples (N = 68).

### **4.3. Procedure**

The study was administered in the computer labs of the university via an online-based learning environment in two consecutive weeks during winter and summer term. In the first week, participants were invited to a 90 minutes session. In this session, they first answered demographic questions about their gender, age, semester, type of study program, internships, prior grades and their use of technology. Then, they received a written classroom case in an open answer format and were asked to reason about one problem in the respective case. Afterwards, they were also requested to describe their own reasoning approach regarding the case (data not included in the analyses).

Participants were also tested for their prior knowledge (PK). This pre-test was followed by the first intervention phase (PK acquisition phase) in which participants were either prompted to read three texts about evidence-based theories (reading conditions) or to read them and additionally create one mind map based on the three texts (mapping conditions).

Before the second intervention phase (case analysis phase), all participants received a short description on how to reason about classroom cases based on models of professional vision including four steps (noticing, description, explanation, solution). In the case analysis phase, students in the problem-solving conditions then received two classroom cases and were again asked to reason about problems in these cases. Students in the worked examples conditions received the identical classroom cases, but also corresponding worked examples with self-explanation prompts that were introduced in a step-wise fashion (see 2.3).

In the second week, again within a maximum time frame of 90 minutes, the case analysis phase continued in which participants were to reason about a third case. In addition, a post-test was administered. The post-test consisted of another classroom case, in which all participants were to reason about problems in this case without any guidance. Then again, participants described their reasoning process (data not included in the analyses) and were tested for their PK. At the end, all participants were able to study the correct solutions of the PK test and exemplary solutions on how to reason about one of the classroom cases.

**Table 1**

*Overview of the study procedure*

Study element	Scheduled time (minutes)
<i>Pretest</i>	
Demographics	5
Unguided reasoning about a case	10
Description of own reasoning	5
PK test	10
<i>Intervention</i>	
PK acquisition phase	76
Reading theory texts vs. mapping theory texts	20
Information on reasoning	3
Case analysis phase	
Case 1: Problem solving vs. studying worked example	17
Case 2: Problem solving vs. studying worked example	17
Case 3: Problem solving vs. studying worked example	17
<i>Posttest</i>	
Unguided reasoning about a case	17
Description of own reasoning	10
PK test	10

### 4.3. Material

The PK acquisition phase was based on three texts dedicated to the ICAP framework (Chi, 2009; Chi & Wylie, 2014), CLT (CLT; Sweller et al., 2019) and quality dimensions of teaching (QDT; Kunter & Voss, 2011). All three texts were identical in

length (493 words). An example of a theory text (CLT) can be found in Appendix A. Participants received the texts as printed material. Students in the reading as well as the mapping conditions received the same prompt in the learning environment: “Please attentively read the theory texts regarding the ICAP-model, Cognitive Load Theory and the dimension of teaching quality that you find upside down on your desk”. Students in the mapping conditions were further instructed by the learning environment to create a combined mind map (visualization) of all the three theory texts in which the most important terms of the three theories would occur and be linked to each other. Visualizations were to be created on a sheet of paper. The learning environment informed students from all conditions that they would have 20 minutes after which they would be forwarded to the next page in the environment. Also, the learning environment prompted students to use all of the time to read or to create the visualization and suggested that all text content would be important in order to professionally analyze the subsequent cases.

The case analysis phase consisted of three digitally presented cases which described lessons of three teachers that used different technological tools in order to enhance their teaching. Each of these cases was constructed in a way that it contained between ten and twelve problems in teachers’ technology-enhanced teaching based on the three theories outlined above (e.g., provision of hypertext by teacher without any further instruction that engages students in other than passive learning activities; high extraneous load due to lack of guidelines or support on how to perform an online search). Descriptions did not include any information on lesson content as we intended to measure TPK, and not TPACK. Length of the cases was between 393 and 412 words. An example of a case is depicted in Appendix B.

Students in the problem-solving conditions were prompted to analyze three problems in the respective cases in an open-ended format. Participants in the worked examples conditions also received the three cases, but instead of prompting them to analyze the problems in each of the cases, they were requested to attentively read the corresponding exemplary case analysis by a certain fictitious student (e.g., Lea). To control for time on task, participants were informed to spend 17 minutes analyzing each of the cases. Each of the case analyses consisted of three problems that were analyzed. An analysis of a problem comprised a description of the four steps (noticing, description, explanation, solution) of professional vision implemented by the fictitious student. These steps were introduced by a short general description of how these steps should be executed. Each step was accompanied by two self-explanation prompts. The first prompt asked participants to mentally explain to oneself why the fictitious student has written this answer down the way she or he did. The second prompt requested participants to (mentally) consider if they would have written down the same as the fictitious student and to (mentally) reflect upon why or why not. An example for an analysis of one problem is depicted in Appendix C. Each reasoning step was represented on a separate page. Participants were automatically forwarded from one reasoning step to the next. While participants had 60 seconds each to read and reflect upon the first two steps (identification and description), the other two steps (explanation and solution) were visible for 90 seconds. Thus, studying one worked example or one case analysis took 17 minutes in total.

## **4.4. Measures**

### **4.4.1. PK**

Participants' PK was assessed during post-test via twelve multiple-choice questions that tapped pre-service teachers' knowledge about ICAP, CLT and QDT as presented in the texts. Multiple-choice items were developed by two content experts in the field of teaching and learning. Each evidence-based theory was measured by means of four multiple-choice questions. For each multiple-choice question, four possible answers were presented. Each of them could be either correct or false. Hence, the theoretical maximum was 48 points. The internal consistency of the test was acceptable (Cronbach's  $\alpha = .68$ ).

### **4.4.2. TPK-PV**

Pre-service teachers' TPK-PV was measured on the basis of their open-ended answers to a classroom case presented in the post-test. The case was comparable in length (424 words) and number of problems (13 problems) to the cases participants worked with in the case analysis phase. Participants were prompted to analyze three problems of the case. Their answers were segmented in a content-based manner, in that every problem mentioned and the corresponding analysis was separated from other problems and corresponding analyses. Based on conventions regarding the quantity of coding for reliability (between 10% and 20%; Wecker et al., 2012), 11% of the data were segmented by two independent trained raters. Interrater reliability regarding segmentation was determined based on suggestions of Strijbos et al. (2006) to take potential overlap of segment boundaries from the perspective of the different raters into account when computing proportion agreement of raters. Interrater-agreement was very good from the perspective of both coders (97% and 96%). The remaining data was segmented by one rater.

*Formal quality.* In order to determine the occurrence of knowledge-based reasoning components (description, explanation, solution; see Table 2), the problems that were identified by a participant were coded based on a coding scheme with three variables, one for each component. A segment was coded as “component does not occur in the segment” (0) or “component occurs in the segment” (1). For all the components 10% of segments were coded by two independent trained raters. An acceptable to good interrater reliability was achieved (see Table 2). The remaining data was coded by one rater. As explanation and solution are understood as the main quality indicators of professional vision (van Es, 2011; van Es & Sherin, 2002), only these two components were included in further analyses. For this purpose, a combined score of explanation and solution was averaged across all segments with a theoretical maximum of 2.

*Content quality.* To determine the content quality of TPK-PV, participants’ noticing of relevant problems and the quality of their explanation and solution were measured. A coding scheme with two categories was developed to analyze noticing. If participants did not identify a relevant problem in their problem analysis, the segment was coded with 0. If they identified a relevant problem according to the sample solution developed by the two content experts based on the theory texts, the segment was coded with 1 (see Table 2). Based on 10% of segments the interrater reliability of the two independent trained raters was perfect (Cohen’s  $\kappa = 1.00$ ). The remaining data was coded by only one rater. For further analyses, a mean across all segments was calculated.

Content quality of participants’ explanations and solutions was again assessed based on the segmented problem analyses of participants. We developed two coding schemes (see Table 2). Description as a negligible component of professional vision was not investigated any further within this study. Participants’ explanations and

solutions received codes from “no use of scientific theories” (0) to “accurate use of scientific theories” (3). The coding of the two components was only realized for segments that included explanations or solutions as form components. Around 12% of explanation and 14% of solution form segments were coded by two independent trained raters. Interrater reliability was good (see Table 2). The remaining data was coded by one rater. Means across all explanation and all solution segments were used in further data analyses.

**Table 2**

*Coding scheme for formal quality, content quality and quality of maps with interrater reliability indicators*

Name	Description	Prototypical examples	Interrater reliability
Formal quality			
Description	Description of a problem in own words	“The teacher scheduled too much time for showing expert videos.”, “The funny cartoons on the slides might pose a problem.”	Cohen’s $k = .83$ (Pre) Cohen’s $k = .82$ (Post)
Explanation	Classification of a problem and/or illustrations of problem-related cause-effect relationships	“The lack of students’ span of attention might have caused them to not focus on the video, but instead to talk to each other.”, “According to Cognitive Load Theory, the use of cartoons that are irrelevant to the lessons’ topic might induce extraneous load on learners.”	Cohen’s $k = .72$ (Pre) Cohen’s $k = .69$ (Post)
Solution	Development of goals and/or measures to improve the problem situation	“The teacher should have split up the video into different segments and ask comprehension questions after each segment.”, “In order to reduce cognitive load, the teacher should remove the irrelevant cartoons from the slides. Instead, she might integrate cartoons relevant to the topic on hand.”	Cohen’s $k = .89$ (Pre) Cohen’s $k = .78$ (Post)
Content quality			
Noticing	Quotation of a problematic aspect in line with sample solution based on scientific theories	“After entering the solution, the correct answer is displayed to students.”, “When comprehension questions occur, the teacher refers the students to other group members and the possibilities of the internet.”	Cohen’s $k = 1.00$
Explanation	No use of scientific theories to explain problem	“Students who are not involved in hands-on classroom activities will not improve their learning.”	ICC (2,1) = .91
	Non-accurate use of scientific theories to explain problem	“According to the ICAP framework, engagement in passive learning activities as shown by students in the classroom case is effective for student learning.”	
	Partly accurate use of scientific theories to explain problem	“According to the ICAP framework, engagement in receptive learning activities as shown by students in the classroom case is not effective for student learning.”	
	Accurate use of scientific theories to explain problem	“According to the ICAP framework, engagement as shown by students in the classroom case is assumed to only afford isolated storing processes.”	

		Consequently, they are expected to facilitate students' learning outcomes only to a minor degree (compared to other types of learning activities)."	
Solution	No use of scientific theories to solve problem	"In order to facilitate students' learning, the teacher should rework the slides to make them more comprehensible."	ICC (2,1) = .79
	Non-accurate use of scientific theories to solve problem	"In order to facilitate students' knowledge acquisition, the teacher should aim at a high intrinsic load of students by presenting more text on the slides."	
	Partly accurate use of scientific theories to solve problem	"In order to facilitate students' knowledge acquisition, the teacher should aim at reducing students' extraneous load by presenting more text on the slides."	
	Accurate use of scientific theories to solve problem	"In order to facilitate students' knowledge acquisition, the teacher should aim at reducing students' extraneous load by eliminating irrelevant information such as the cartoons."	
Quality of maps			
	Incomplete – less than majority of central theory elements mentioned	"classroom management" (QDT)	ICAP: ICC (2,1) = 1.00
	Rather incomplete – majority of central theory elements mentioned	"extraneous load, intrinsic load, germane load" (CLT)	CLT: ICC (2,1) = .95
	Rather complete – majority of central elements and at least one corresponding second-order element (such as characteristics, relationships, consequences, and examples) for the majority of central elements mentioned	"passive → reading (example activity), active → underlining text (example activity), constructive → mapping (example activity), interactive → discussing in small groups (example activity)" (ICAP)	QDT: ICC (2,1) = 1.00
	Complete – majority of central and second-order elements mentioned	"intrinsic load → complexity of content (characteristic) → dependent on prior knowledge + element interactivity (relationship), extraneous load → induced by learning environment characteristics not related to knowledge construction (characteristic), irrelevant illustration (example), germane load → induced by processes relevant to learning (characteristic), comparison of information (example), adding up of types of load → cognitive overload (relationship) → reduction of extraneous load (consequence)" (CLT)	

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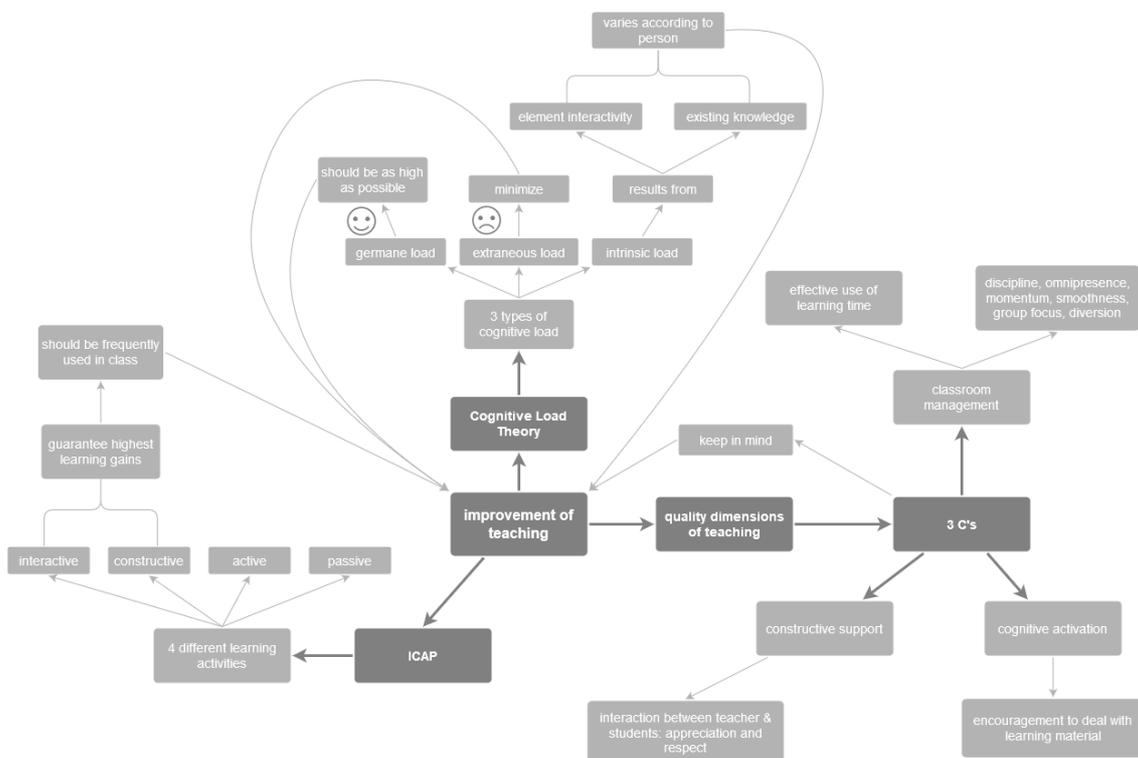
*Note.* CLT = Cognitive Load Theory, ICAP = Interactive-Constructive-Active-Passive framework; QDT = Quality dimensions of teaching.

#### 4.4.3. Quality of maps

The assessment of the quality of participants' maps was realized by three coding schemes, one for each evidence-based theory (ICAP, CLT, QDT; coding scheme see Table 2). The coding schemes were based on the central theory elements represented in the texts. Participants' visualizations (example see Figure 2) were marked from incomplete (0) to complete (3) depending on the degree of elements represented in participants' maps relative to the central theory elements in the text. 18% of participants' maps were rated by two independent trained raters. Interrater reliability was excellent for all three coding aspects (see Table 2). The remaining data was again coded by one rater. In the following analysis, the mean of the three scores for the different theories was used as indicator of quality of maps.

**Figure 2**

*Example map created by a participant*



*Note.* This map was digitally reworked in order to include translations.

#### **4.4.5. Control variables**

To control for participants' prior knowledge, a test to assess participants' prior PK and a test to assess the prior formal quality were used during pre-test. Participants' PK was measured with the same items as described earlier in the section PK (2.4.1.). The internal consistency of the test was acceptable (Cronbach's  $\alpha = .65$ ).

To assess prior formal quality, a short version of the second intervention and post-test cases was developed which was reduced in length (212 words). Participants were requested to analyze one of the problems in an open-ended manner. There was no further guidance provided. Analogous to the post-test measure, a problem-based segmentation was performed. First, 10% of the data were segmented by two independent raters. Interrater reliability was good from the perspective of both raters (87% and 88%). Then, analogous to the post-test, segments were coded for description, explanation and solution with code 0 referring to no occurrence of the respective component and code 1 meaning that the respective component occurred in the segment. Interrater reliability based on 13% (explanation), 14% (description) and 15% (solution) of the data revealed good to very good values (see Table 2). For further analyses, a combined score of explanation and solution was averaged across all segments.

#### **4.5. Statistical analyses**

To test our hypotheses, we performed structural equation modeling with maximum likelihood estimation with robust standard errors (MLR) in Mplus 8 (Muthén & Muthén, 2017) as it offers the opportunity to include multiple independent and outcome variables simultaneously and specify their relationships (Hoyle, 2015; Ullman & Bentler, 2012).

To test Hypothesis 1a which assumed that learning by mapping should result in higher PK and content quality than mere reading, we used mapping and prior PK as predictors, and PK, noticing, content quality of explanations and content quality of solutions as outcome variables. All variables were included as manifest variables. As it is thus considered a saturated model, fit indices are not presented. In order to determine the unique contribution of mapping in explaining the variance of the outcome variables ( $\Delta R^2$ ), a second model was estimated with prior PK as the only predictor.

In order to test Hypothesis 1b which assumed that the quality of maps should be positively associated with PK and content quality, we used quality of maps and prior PK as predictor variable and PK, noticing, content quality of explanations and content quality of solutions as outcome variables (saturated model). Again, a second model with quality of maps as single predictor was estimated in order to determine the unique contribution of quality of maps to the explanation of variance in the outcome variables.

To analyze the hypothesized positive effects of learning by worked examples compared to problem solving on formal quality (H2a) and content quality (H2b), we modeled paths from prior formal quality and worked examples on the formal quality and from prior PK and worked examples on noticing, content quality of explanation and content quality of solution. A second model with worked examples as single predictor was established with the aim to assess the unique explained variance of worked examples in the outcome variables.

## **5. Results**

### **5.1. Preliminary analyses**

In order to determine if pre-service teachers who participated in the winter term 2018/19 or summer term 2019 were different from each other regarding their prerequisites, we

analyzed the effect of cohort on prior PK and on prior formal quality via *t*-tests. We found no significant differences, neither for prior PK ( $t(250) = 0.69, p = .50$ ) nor for prior formal quality ( $t(250) = 1.40, p = .16$ ).

## 5.2. H1: Results on effects of mapping and quality of maps on PK and content quality of TPK-PV

Descriptive data in Table 3 illustrate that means for noticing were rather high for students of both mapping and reading conditions. Nevertheless, students of the reading conditions demonstrated a problem noticing rate of 94% percent, while students of the mapping conditions only reached a rate of 86% percent. In contrast, means in reading conditions and mapping conditions were comparable for explanations and also equally low for solutions.

**Table 3**

*Descriptive data for reading and mapping conditions*

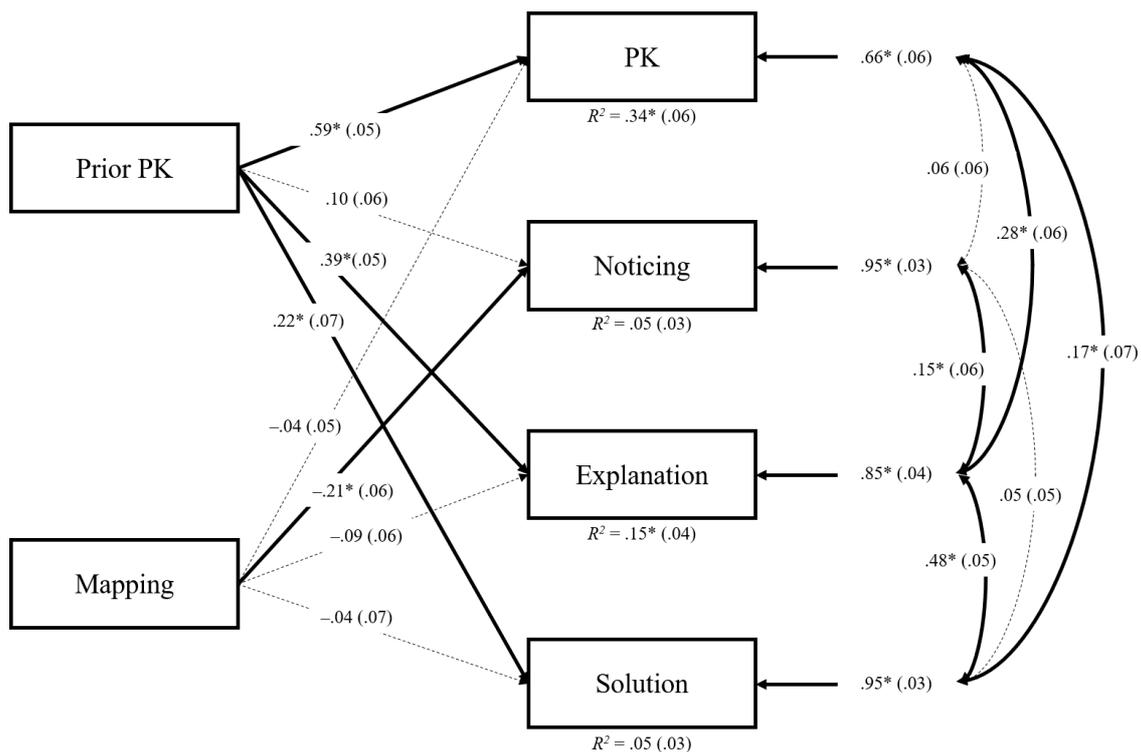
Variable	Theoretical maximum	Reading		Mapping	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
<i>Pre-test</i>					
Prior PK	48.00	33.75	5.05	34.53	4.37
<i>Post-test</i>					
PK	48.00	36.94	4.85	36.99	4.16
Content quality					
Noticing	1.00	0.94	0.16	0.86	0.23
Explanation	3.00	1.24	1.10	1.18	1.05
Solution	3.00	0.56	0.86	0.57	0.93
Quality of maps	3.00			1.53	0.64

*Note.* Means (*M*) and standard deviations (*SD*) for PK, formal quality, noticing, content quality of explanation, content quality of solution and quality of maps for pre-service teachers in reading and mapping conditions.

Results of structural equation modeling showed that, overall, prior PK turned out to be a significant predictor for PK and content quality, except for noticing. In contrast, mapping significantly predicted noticing, but surprisingly in a negative direction. However, the unique variance explained by mapping was small ( $\Delta R^2 = .04$ ,  $\Delta SE = .02$ ). Thus, in the model with prior PK and mapping, the explained variance of noticing by prior PK and mapping was not significant. Mapping neither functioned as significant predictor for PK nor for content quality of explanation and solution. Results can be found in Figure 3.

**Figure 3**

*Results of structural equation modeling the effects of prior PK and mapping*



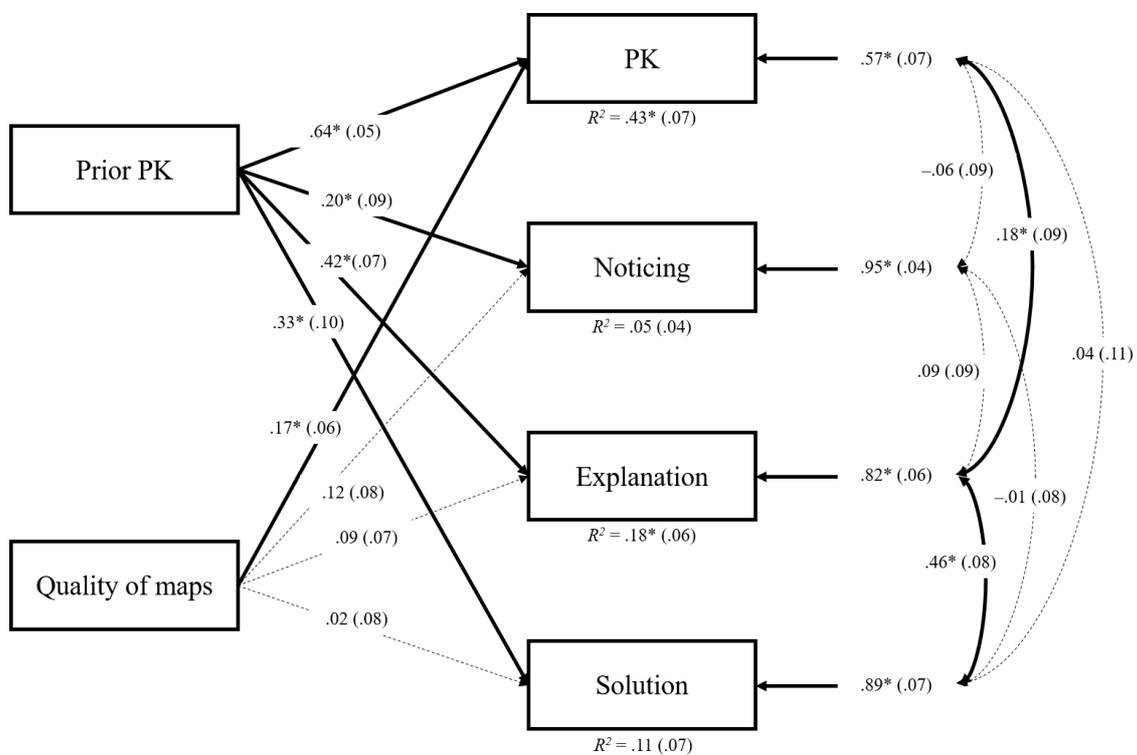
*Note.* Presented are the standardized coefficients and standard errors in parentheses. \* $p < .05$ .

Results of structural equation modeling on the associations of quality of maps with PK and content quality illustrated the following pattern: While prior PK

significantly predicted PK and content quality, quality of maps only functioned as predictor for PK, but not for content quality. The unique contribution of quality of maps to the explanation of variance in PK, again determined by a comparison with a second model with prior PK as single predictor, was rather small ( $\Delta R^2 = .09$ ,  $\Delta SE = .02$ ). Results are detailed in Figure 4.

**Figure 4**

*Results of structural equation modeling the effects of prior PK and quality of maps*



*Note.* Presented are the standardized coefficients and standard errors in parentheses. \* $p < .05$ .

### 5.3. H2: Results on effects of worked examples on formal and content quality of TPK-PV

With regard to formal quality, descriptive data in Table 3 revealed that participants in the worked example and problem-solving conditions demonstrated rather high, but comparable means in the pretest. Even though means increased in both conditions from

pre- to post-test, the extent of increase was similar in worked example and problem-solving conditions.

With regard to content quality, descriptive data in Table 3 indicate that participants in worked examples as well as problem-solving conditions reached rather high scores on noticing. Still, while students of the problem-solving conditions detected relevant problems in more than eight out of ten times, students of the worked examples conditions even recognized relevant problems in over nine out of ten times. In contrast to the high means for noticing, especially students in the problem-solving conditions performed rather poorly in the explanation and even more so in the solution of cases. For both factors, participants in the worked examples conditions reached more than twice as high scores than participants in the problem-solving conditions. In total, standard deviations imply that values of participants varied to a large degree within the conditions for explanation and solution.

**Table 4**

*Descriptive data for problem solving and worked example conditions*

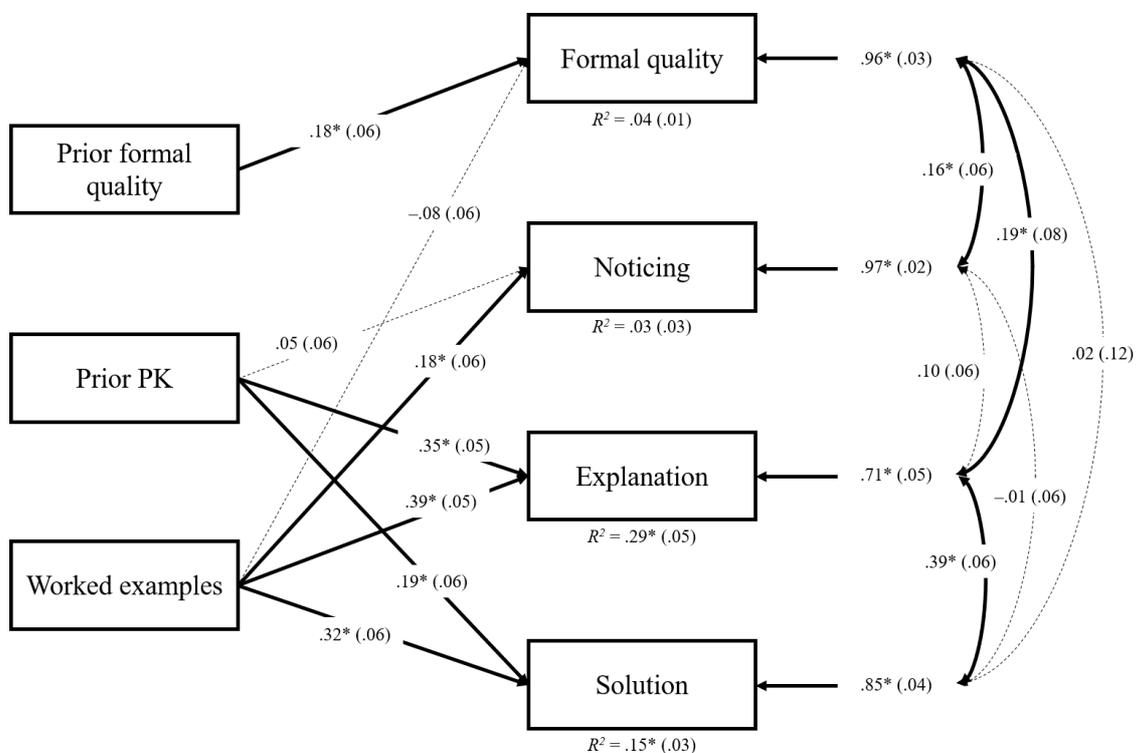
Variable	Theoretical maximum	Problem solving		Worked examples	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
<i>Pre-test</i>					
Prior PK	48.00	33.94	4.90	34.34	4.56
Prior formal quality	2.00	1.35	0.51	1.31	0.47
<i>Post-test</i>					
PK	48.00	36.58	4.21	37.35	4.78
Content quality					
Noticing	1.00	0.86	0.23	0.94	0.16
Explanation	3.00	0.71	0.88	1.72	1.01
Solution	3.00	0.27	0.65	0.88	0.99
Formal quality	2.00	1.74	0.29	1.78	0.33

*Note.* Means (*M*) and standard deviations (*SD*) for PK, formal quality, noticing, content quality of explanation, content quality of solution and quality of maps for pre-service teachers in problem solving and worked examples conditions.

A structural equation model showed a good fit to the data ( $df = 4$ ,  $\chi^2 = 6.06$ ,  $p = .20$ , RMSEA = .05, CFI = .99, TLI = .95, SRMR = .03). Results point to significant associations of pretest indicators (prior PK and prior formal quality) with formal and content quality (except for noticing). Furthermore, learning with worked examples functioned as a significant predictor for noticing, content quality of explanation and content quality of solution. While worked examples only contributed to a minor, non-significant degree to the explanation of variance in noticing ( $\Delta R^2 = .03$ ,  $\Delta SE = .01$ ), their unique contribution was moderate for content quality of explanation ( $\Delta R^2 = .15$ ,  $\Delta SE = .04$ ) and small to moderate for content quality of solution ( $\Delta R^2 = .10$ ,  $\Delta SE = .02$ , see Figure 5).

**Figure 5**

*Results of structural equation modeling the effects of prior formal quality, PK and worked examples*



*Note.* Presented are the standardized coefficients and standard errors in parentheses. \* $p < .05$ .

## **6. Discussion**

Teachers and their knowledge on how to effectively implement technology in classroom settings play an important role in order to exploit the potentials of technology to support students' learning processes. The TPACK framework (Koehler & Mishra, 2008; Mishra & Koehler, 2006) provides a comprehensive overview of the types of knowledge teachers need to have in order to do so. However, situation-specific skills in terms of professional vision have hardly been in the scope of TPACK research so far. Thus, this study sought to provide a reasonable account for how to connect research on TPACK and on professional vision (TPACK-PV). In this regard, studies indicate that there is a need to foster the content quality as well as the formal quality of pre-service teachers' TPACK-PV.

While learning by mapping seems to be a promising approach to enhance pre-service teachers' conceptual knowledge and consequently the content quality of their TPACK-PV, research led us to expect that learning from worked examples might prove to be successful to enhance the form and content quality of pre-service teachers' TPACK-PV. Consequently, we investigated the effects of learning by mapping (Fiorella & Mayer, 2015) and learning from worked examples (Renkl, 2014) on pre-service teachers' content and form quality of their TPK-PV in the context of case-based learning. By and large, our results demonstrate the potentials of two different instructional scaffolding measures for fostering TPK-PV. Yet, the pattern of results was not consistent. In the following, we will discuss the results in more depth.

### **6.1. H1: Discussion of effects of mapping and quality of maps on PK and content quality of TPK-PV**

Regarding the effect of mapping on PK and content quality of TPK-PV (H1a), at a general level, our results seem to contradict assumptions about the positive impact of mapping as a constructive or generative activity compared to lower-quality learning activities outlined in learning frameworks (Chi & Wylie, 2014; Mayer, 2014). Yet, once participants managed to create high quality maps, they at least gained more PK. Nevertheless, these students still had difficulties translating their higher PK into a higher content quality of their analyses (H1b).

These results seem to indicate that learning by mapping might at least have positive effects on pre-service teachers' declarative knowledge (even if not on more complex situation-specific skills), provided that pre-service teachers are able to apply the mapping strategy appropriately and produce more complete maps. Thus, results are roughly in line with results confirming the prognostic drawing effect (Scheiter et al., 2017; Schmeck et al., 2014; Schwamborn et al., 2010). However, results also show that many students had problems creating high-quality maps, which could have prevented them to benefit from the potentials of learning by mapping. These problems might have originated in students' strong focus on the mapping process (How do I construct a map? How should it look like?) instead of a deep processing of the textual information (Schmidgall et al., 2019) due to the demanding nature of mapping as a strategy (Stull & Mayer, 2007). In this regard, empirical findings suggest that more detailed instructions on how to construct high-quality maps might lead to more positive effects (Hilbert et al., 2008; Hilbert & Renkl, 2009). Consequently, in order to exploit the potentials of constructive and generative learning activities, we see the need to further support pre-service teachers in the acquisition of the mapping strategy.

## **6.2. H2: Discussion of effects of worked examples on formal and content quality of TPK-PV**

Regarding the effects of worked examples on the content quality of pre-service teachers' TPK-PV (H2b), we found that participants who learned from worked examples showed better noticing, explanation and solution skills than pre-service teachers who only solved problems. However, worked examples did not result in more complete knowledge-based reasoning processes in terms of formal quality (H2a). Thus, worked examples might only unfold their differential potential for the adequate use of scientific theories when reasoning about technology-enhanced learning, which might constitute a more complex subskill than merely performing the reasoning components.

Results on the positive effect of worked examples on content quality are in line with the worked example effect (Sweller et al., 1998; Sweller et al., 2019) and general findings in research on worked examples (Crissman, 2006; Klopp & Stark, 2018). Also, a comparison with other approaches facilitating aspects of professional vision or TPACK-PV illustrates that worked examples might be particularly efficient in enhancing the content quality of pre-service teachers' TPK-PV. While in previous studies (Gold et al., 2013; Kramarski & Michalsky, 2009, 2010) training time went up to 60 hours, time attributed to the intervention in our study was considerably shorter with a maximum of 180 minutes. Nevertheless, scores and their ranges suggest that there was still room for improvement for students in the worked examples conditions. In particular, the high variance of scores leads to several questions to be answered: To which degree did pre-service teachers cognitively engage in the self-explanation of worked examples? To which degree were pre-service teachers able to abstract principles from the different worked example instances? Based on the ICAP-framework, it should prove helpful to prompt learners to engage in overt constructive learning activities (writing down answers to self-explanation prompts) instead of only prompting them to reflect about

them without making any notes: First, the prompting of this kind of overt behavior increases the possibility that learners interact with the material as intended (Chi & Wylie, 2014). Second, learners' outputs allow for the investigation of their quality as an approximation of their cognitive processes. Consequently, in further studies, it might be promising to prompt learners to create written self-explanations (Hefter et al., 2015; Heitzmann et al., 2018; Renkl, 2014; Schworm & Renkl, 2007). Still, aspects of cognitive load should not stay unconsidered as further tasks might take away capacity necessary for germane cognitive processing of the worked examples (Renkl, 2014).

With regard to the lacking differential effect of worked examples on the formal quality of pre-service teachers' TPK-PV, descriptive results illustrate that pre-service teachers seemed to already have a rather good understanding of processes that are relevant in order to reason about technology-enhanced teaching. Thus, the basic instructions on how to reason about classroom cases that all participants received irrespective of their condition might have sufficed in order to improve the formal quality. Consequently, less complex forms of guidance such as prompting might just be adequate to foster the formal quality of pre-service teachers' TPK-PV as demonstrated in research on professional vision (Santagata & Angelici, 2010; Santagata & Guarino, 2011; van Es & Sherin, 2002).

## **7. Limitations and conclusions**

To our knowledge, our study is one of the first to make an explicit association between TPACK research (Koehler & Mishra, 2008; Mishra & Koehler, 2006) and research on professional vision (Seidel & Stürmer, 2014; van Es & Sherin, 2002) by not only investigating pre-service teachers' actual TPK-PV, but also trying to scaffold their TPK-PV. However, several aspects need to be addressed that limit the explanatory

power of the study. First, the study only focused on pre-service teachers' TPK-PV, not their TPACK-PV. Hence, results might not be transferable to subject matter-related aspects of technology-related teaching skills. Therefore, in future research, an adaptation of the selected research approach to different subject domains would be of great interest. Second, based on the presented data no claims can be made about long-term effects of the intervention. This is particularly true as our intervention is considered a short-term intervention in comparison to other approaches taken (Gold et al., 2013; Kramarski & Michalsky, 2009, 2010). Nevertheless, as results on the worked-examples intervention are already promising, a longer intervention might enlarge the found effects. Third, our study lacked additional measures to better understand the effects of the relevant factors. While we were able to measure the quality of pre-service teachers' maps, we did not measure cognitive load during reading and mapping. Fourth, it would have been insightful to have a written output of students' self-explanation processes to be able to better explain in which way worked examples helped or did not help students to acquire TPK-PV. And finally, results might have underestimated the content quality of pre-service teachers' TPK-PV as raters were only able to detect the adequate use of empirically-based theories when participants explicitly mentioned theories or theory elements. However, in certain cases students might have referred to theory elements without stating them as theory elements, but by translating them into their own wording or combining them with subjective theories and experiential knowledge.

Despite these shortcomings, this study contributes to research on TPACK in the two following ways: First, we made a first attempt in replicating effects of mapping and worked examples in the context of research on TPACK and professional vision in which experimental intervention studies are still rare up to date. We could show that pre-

service teachers' TPACK-related professional vision can be facilitated by means of learning from authentic cases combined with further scaffolding measures. Even though effects did not show on all facets, potentials of learning by mapping and learning from worked examples could be identified.

Second, the study enhances a better theoretical understanding of TPACK by focusing on the spectrum between TPACK as knowledge and TPACK as competence, in that we conceptualized TPACK as a situation-specific skill based on concepts of professional vision. We introduced a differentiation between formal and content quality of TPACK-PV which has not been elaborated on yet in research on professional vision.

Overall, our results may provide valuable support for designers of learning environments that aim at fostering pre-service teachers' development of TPACK-PV. While generally, learning by mapping did not turn out as a superior learning strategy to mere reading of texts, our results indicate that quality of maps should be considered as a moderating factor when answering the question of how learning by mapping works. It might prove particularly useful to take learner-related (e.g., prior knowledge of content/method) as well as instructional factors (e.g., instructional support) at the same time into account when implementing learning environments targeted at the development of TPACK-PV. As opposed to learning by mapping, learning from worked examples seems to be a reliable scaffolding approach, at least in the context of acquiring more complex situation-specific technology-related teaching skills. Thus, we suggest to implement worked examples as a concrete measure within existing training measures in order to better prepare future teachers to use the potentials of technology-enhanced teaching and learning.

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## Appendix

### **A: Example of an evidence-based theory text (Cognitive Load Theory, translated and adapted from Leutner et al., 2014)**

Cognitive Load Theory (CLT; Sweller, 1999) generally refers to learning and problem solving and has also proven to be reliable in the context of multimedia learning. According to the theory, three types of cognitive load can occur in working memory while learning or problem solving that influence the comprehension of learning content and learning outcomes. These types are (a) intrinsic load, (b) extraneous load and (c) germane cognitive load.

Intrinsic cognitive load describes the proportion of cognitive load that is caused by the complexity and difficulty of the learning content. The degree to which a certain learning content is considered easy or difficult depends on two aspects: learners' prior knowledge (in terms of the availability of schemata that are relevant to learning to encode content information) as well as element interactivity. This expression refers to how many knowledge elements a learner needs to keep active in working memory in order to understand or study the learning content. The acquisition of a foreign language might be named as an example: ramming vocabulary lists might not cause a particularly high intrinsic load as single words may be studied one after each other; element interactivity is low in this case. In contrast, intrinsic load may be much higher for studying grammar rules, as different elements that have to be understood and studied are related to each other.

Extraneous load refers the proportion of cognitive load that is caused by the learning material or learning environment, but is not directly related to or even disturbs knowledge construction processes. Extraneous load occurs if a learning surrounding is characterized by the presence of disturbing/distracting aspects such as non-relevant illustrations that are not related to the actual learning content or if information that have to be connected with each other are presented separately or if this information is difficult to find. In such cases of suboptimal design, learners need to invest increased cognitive capacity in order to filter relevant information from the learning material. The capacity used up by extraneous cognitive processes is then not available anymore for knowledge construction processes that are related to the material to be learned.

Germane cognitive load denotes these proportions of cognitive load that are caused by actual meaningful learning. This load results from an engagement in deep cognitive processes such as elaborating, organizing, contrasting and inferring.

According to Cognitive Load Theory, the three forms of cognitive load work additively, which means that they add up to a cumulative load which may take working memory capacity up at some point during learning. If this cumulative load exceeds the capacity of the working memory, cognitive overload occurs which causes learning to be less effective. With regard to the design of learning material and learning environments, one goal should thus be to minimize the instructionally caused extraneous load in order to ensure that students have sufficient capacity for cognitive activities relevant to learning. This is particularly true when students possess low prior knowledge about the learning content.

## **B: Example of a technology-enhanced classroom case**

Mr. Frey is a fan of having his students work collaboratively. He feels that for his students, it is sometimes easier to explain certain aspects to their fellow students because they share the same perspective. Thanks to the digitalization of his school, he is now even able to use digital tools to enhance collaborative learning what makes things a lot easier.

In today's lesson, he forms groups of two and has each dyad develop a glossary with a tablet in their learning management system. Students are supposed to use their material of the last few lessons to write down the most important expressions and rules that they have learned in the last few lessons in order to repeat them. He asks one person of each group to do the writing. One can perceive studious typing by the students, however only few of them are talking. Mr. Frey has expected more ambiguities to occur. Therefore, the following comparison of students' errors with the exemplary glossary of Mr. Frey is done quickly.

In order to apply the acquired knowledge, the groups are then asked to watch two animations together that neither contain text nor sound. While one of the two learning partners is watching the animation, the other learner is supposed to explain what can be seen in the animation. Students are then supposed to switch roles for the second animation. Following this, Mr. Frey hands out a text in which the processes shown in the simulation are described in detail in order to correct potentially wrong explanations. He asks students to compare the description and the animation by first reading the text and then watching the animation once again.

Towards the end of the lesson, Mr. Frey wants the groups to compete in a quiz with their tablets. However, some students report that they cannot register for the quiz tool. In line with principles of self-regulated learning, Mr. Frey asks students to solve this problem on their own. As usual, when small interruptions occur, the other students are allowed to use their class chat app to communicate in order to minimize the noise. Ten minutes later, the quiz begins. Mr. Frey has chosen easy question so that all students receive positive feedback and are motivated when leaving the class. Therefore, he perceives that students only need some seconds to type in their answer (as compared to one minute which is set as time limit in the quiz tool). And the chart depicting the results shows that all teams have answered the questions 100% correct. He is satisfied with the results and praises his students for doing well.

## **C: Example of a worked example**

**Step 1: Identification of the problem:** The search for situations, which are considered problematic with regard to classroom-related teaching and learning processes, based on scientific concepts, theories and findings.

*Andreas identified the following problem: "He asks one person of each group to do the writing. One can perceive studious typing by the students, however only few of them are talking. Mr. Frey has expected more ambiguities to occur."*

**Step 2: Description of the problem:** The neutral description of the problem situation in one's own words.

*Andreas wrote the following: "The students were to create a glossary together. One person was supposed to do the writing. The task of the other person was not defined any*

*further. An exchange between the students only takes place to a relatively low degree.”*

**Step 3: Explanation of the problem:** The use of scientific terms, theories and findings in order to categorize and conceptualize the problem.

*The written analysis of Andreas includes the following explanation: “For an interactive learning activity according to the ICAP framework (Chi, 2009; Chi & Wylie, 2014), it is necessary that students relate to each other by explaining something to each other or discussing something. This only seems to take place to a limited extent, as there is more typing than talking in the classroom. Due to the different allocation of responsibilities it might be more likely that the person who writes (a rather active or constructive activity) engages in more high-quality knowledge construction processes than the person who does not type (a rather passive activity).”*

**Step 4: Solution of the problem:** The general and situation-specific illustration of opportunities to solve the problem based on scientific concepts, theories and findings.

*Andreas realized this step in the following way: “Based on the ICAP framework (Chi, 2009; Chi & Wylie, 2014), Mr. Frey should try to support students to really engage in interactive learning activities. To this end, he might attribute different roles to the students: On a rotating basis, one of the two might suggest a new glossary entry, while the other student critically examines the suggestion, gives feedback and states reasons for the feedback.”*