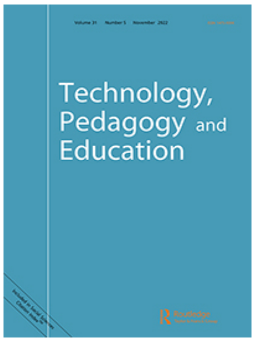

Technology, Pedagogy and Education

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rtpe20

Using technology to promote student learning? An analysis of pre- and in-service teachers' lesson plans

Christina Wekerle & Ingo Kollar

TECHNOLOGY, PEDAGOGY AND EDUCATION
2022, VOL. 31, NO. 5, 597–614
https://doi.org/10.1080/1475939X.2022.2083669

Routledge
Taylor & Francis Group

OPEN ACCESS
Check for updates

Using technology to promote student learning? An analysis of pre- and in-service teachers' lesson plans

Christina Wekerle and Ingo Kollar

Chair of Educational Psychology, University of Augsburg, Augsburg, Germany

ABSTRACT

Technology may promote student engagement in high-level learning processes in the classroom. Yet, whether teachers really exploit technology's potential to support student learning depends on their expertise. The authors compared pre-service and technology-experienced in-service teachers' reasoning about technology-enhanced lessons by means of lesson plans. The authors assumed that technology-experienced teachers' lesson plans would target more high-level learning activities than those of pre-service teachers. They asked N = 134 pre-service and technology-experienced in-service teachers to plan an ideal technology-enhanced classroom lesson. The teachers were requested to report the types of learning activities they would have students engage in, both during technology-enhanced and non-technology-enhanced lesson activities. As assumed, in-service teachers were more likely to include higher-level technology-enhanced learning activities than pre-service teachers. However, the authors found no differences for non-technology-enhanced learning activities. Based on these findings and further qualitative analyses, implications for curriculum design are drawn.

ARTICLE HISTORY
Received 24 September 2019
Accepted 4 March 2022

KEYWORDS
Teaching expertise; TPACK; ICAP; lesson plans; learning activities

The problem

The use of digital technology is believed to facilitate diverse learning processes in the classroom (Sung et al., 2016). For example, audience response systems have been shown to enhance students' engagement in the classroom (Castillo-Manzano et al., 2016). In collaborative learning settings, group awareness tools may help learners better coordinate their collaborative activities (Janssen & Bodemer, 2013). However, evidence from meta-analyses shows rather small (albeit positive) and heterogeneous effects of digital technology on learning outcomes (e.g., Chauhan, 2017; Cheung & Slavin, 2013; R. F. Schmid et al., 2014; Tamim et al., 2011). One potential explanation for the heterogeneity of these effects concerns how teachers implement digital technology in the classroom. For example, Tamim et al. (2011) found the effect of digital technology use on students' learning outcomes to be significantly larger when teachers used such technology primarily to *support* instruction (e.g., information and communication technology) rather than to *implement* instruction (e.g., computer-based instruction).

These and other results (e.g., Chien et al., 2016; R. F. Schmid et al., 2014) highlight the importance of teachers' technology-related teaching knowledge and the ways in which they use technology at the instructional level to support student learning. A prominent approach that conceptualises and measures this kind of teacher knowledge is the Technological Pedagogical and Content Knowledge (TPACK) model proposed by Mishra and Koehler (2006), see also Koehler and Mishra (2009). Based on

CONTACT Christina Wekerle christina.wekerle@phil.uni-augsburg.de Chair of Educational Psychology, University of Augsburg, Universitätsstr. 10, 86135, Augsburg, Germany

This article has been republished with minor changes. These changes do not impact the academic content of the article.

Shulman's (1986) conceptualisation of pedagogical content knowledge and in order to promote student learning, the model highlights the necessity of productively integrating technological knowledge (TK), pedagogical knowledge (PK) and content knowledge (CK) resulting in combined knowledge components (PCK, TCK, TPK, TPACK).

Even before the COVID-19 pandemic, education policymakers had been increasingly asking teachers to acquire TPACK components in order to better exploit technologies' potential for teaching and learning and had articulated the need for more targeted pre-service teacher education programmes (e.g., Standing Conference of the Ministers of Education and Cultural Affairs, 2019; U.S. Department of Education, 2016). We argue that the design of such teacher education curricula should be informed by comparative empirical research that contrasts pre-service teachers' and technology-experienced in-service teachers' TPACK components. Such comparisons might illustrate pre-service teachers' proposed trajectory by defining technology-experienced in-service teachers' TPACK as a possible target state. The results might thus help to better define learning objectives for pre-service teacher education curricula and understand the prerequisites for pre-service teachers' TPACK development (see Auerbach et al., 2018). However, we suggest that the following two ideas be considered when assessing pre- and in-service teachers' TPACK components:

(1) Students' acquisition of twenty-first-century skills such as creative thinking and collaborative learning is deemed increasingly central to ensuring that they are well-prepared for future challenges in today's interconnected world (Partnership for 21st Century Learning, 2019); however, such skills are not specifically addressed in the TPACK framework. Thus, the TPACK framework does not provide any guidance on what kind of appropriate learning activities students should be prompted to engage in by means of technology (Brantley-Dias & Ertmer, 2013). Given that constructivist approaches are often said to hold particular potential for the acquisition of such skills owing to their greater focus on students' learning processes, many researchers suggest assessing TPACK from a learner-centred, constructivist perspective (Angeli & Valanides, 2009; Chai et al., 2013; Koh et al., 2017; Olofson et al., 2016). In this regard, the ICAP model (Chi, 2009; Chi & Wylie, 2014) might serve as a supplementary framework for evaluating pre-service teachers' TPACK components from a constructivist point of view by differentiating between more and less effective (technology-enhanced) learning activities and relating them to cognitive processes and learning outcomes.

(2) Self-assessment instruments are most commonly used to assess TPACK components in research (Willermark, 2018). However, self-assessment instruments are considered a good measure of teachers' confidence regarding a certain topic, but not their actual knowledge (Law & Chow, 2008; Scherer et al., 2017). Hence, an alternative might be to measure teachers' qualitative reasoning processes in typical teaching-related situations (Heitink et al., 2016) by analysing teachers' lesson plans, which represent a central teaching-related activity that may provide insight into teachers' cognition in the form of pedagogical decision-making (Harris et al., 2010; Willermark, 2018). Moreover, using lesson plans to measure TPACK components is particularly useful in pre-service teacher education, in which there are often limited opportunities for pre-service teachers to teach in real classroom settings (Harris et al., 2010). Finally, lesson plans not only help obtain more in-depth insights into teachers' reasoning concerning the deployment of digital technology, but also their reasoning about the interplay or consequences of technology-enhanced classroom activities for non-technology-enhanced activities. This should contribute to more comprehensive curricular design decisions that might help improve not only pre-service teachers' technology-enhanced teaching, but their teaching overall. Nevertheless, it should be noted that (pre-service) teachers' reasoning processes are only a very rough approximation of teachers' actual teaching with technology and tend to overestimate teachers' TPACK in practice (Heitink et al., 2016, 2017).

Based on the outlined arguments, we aimed to identify relevant indicators for the development of curricular interventions to support pre-service teachers' TPACK development. In doing so, we decided to only focus on teachers' technological pedagogical knowledge (TPK) in this study to be able to make more general assertions about the differences in pre- and in-service teachers' technology-related teaching knowledge independent of content-related factors (in terms of CK, PCK, TCK, TPACK). Consequently, we were interested in the kind of technology-enhanced and non-technology-enhanced learning activities pre-service teachers and in-service teachers envisioned in their lesson plans irrespective of subject matter. We first introduce the ICAP framework as a learner-centred model that helps to determine whether teachers' reasoning in lesson plans has the potential to support students' cognitive processes and learning outcomes. Based on the ICAP model, we then discuss findings that point to possible characteristics of experienced in-service teachers' reasoning with respect to teaching with technology that might be distinguishable from pre-service teachers' reasoning.

Conceptualising teachers' technology-related teaching knowledge from an ICAP perspective

One of teachers' most important tasks is to provide opportunities for students to engage in higher-order learning processes, i.e., cognitive processes that are closely related to knowledge acquisition (Seidel et al., 2002). Of course, teachers are not able to directly observe which cognitive processes students in fact engage in when providing certain (technology-enhanced) learning opportunities. However, by facilitating certain observable (technology-enhanced) learning activities, teachers can at least increase the chance that students are engaging in high-quality knowledge construction processes.

This assumption was put forward by Chi and Wylie (2014) in their ICAP framework, which identifies four types of (visible) learning activities that are believed to be associated with (non-visible) cognitive processes and learning outcomes at different levels of elaboration: passive, active, constructive and interactive. The *passive* mode of engagement refers to learning activities in which students receive information without exhibiting any other type of overt learning behaviour (e.g., watching an online video). At the cognitive level, this typically leads to the rather isolated storage of information in students' knowledge bases, as prior knowledge is not actively triggered. Thus, such knowledge can often only be recalled in the same context. The *active* mode of engagement includes physical actions directed at a learning object (e.g., pausing or fast-forwarding an online video). At the cognitive level, this is believed to lead to the integration of new information with prior knowledge, as the deliberate emphasis students place on certain aspects of the learning material might lead to an activation of prior knowledge. In turn, these processes might allow learners to more easily apply the newly acquired knowledge to similar situations. The *constructive* mode of engagement refers to learning activities in which learners create new learning output that goes beyond the initially provided learning content (e.g., drawing a digital concept map of the information presented in the online video). At the cognitive level, engagement in constructive activities leads students to infer new information based on their integrated knowledge. It also allows learners to transfer their knowledge to new situations and tasks. Finally, the *interactive* mode of engagement refers to learning activities that involve mutual exchange, in which learning partners build on each other's contributions (e.g., writing a review of the online video in a small group with the help of a collaborative text editor). Engagement in interactive activities, according to Chi and Wylie (2014), may result in co-inferring new information with the help of input or inferences from one's learning partners. Consequently, this might give rise to the co-creation of knowledge.

The ICAP hypothesis states that as the cognitive processes associated with the visible learning activities become increasingly elaborate, from 'passive' to 'interactive', higher domain-specific or content-related learning should result. In other words, engagement in *interactive* learning activities should lead to higher earning gains than constructive learning activities, which should in turn lead to higher learning gains than active learning activities. The learning gains associated with engagement in passive learning activities should be lowest.

Re-examinations of existing laboratory and classroom studies by Chi (2009) and Chi and Wylie (2014) as well as results by Menekse et al. (2013) seem to support the ICAP hypothesis. Menekse et al. (2013) analysed the effects of all four modes of engagement on learning outcomes. In the *passive* condition, they asked participants to read a text; in the *active* condition, to read and highlight passages from the text; in the *constructive* condition, to interpret a graph containing information from the text; in the *interactive* condition, to interpret a graph together with a partner. The results showed significant higher increases in students' content knowledge from pre- to post-test in the interactive compared with the constructive condition, the constructive compared with the active condition and the active compared with the passive condition.

Thus, based on the ICAP model, it would be interesting to determine to what extent pre-service teachers and technology-savvy in-service teachers reason about the use of digital technology to trigger students' engagement in the different modes of learning activities.

What can pre-service teachers learn from technology-experienced in-service teachers' reasoning?

How teachers reason and make use of digital technology in the classroom might be influenced by several factors. One important factor is teachers' teaching experience (Voogt et al., 2016). In order to better support pre-service teachers' development of TPK-based reasoning, applying the relative approach to expertise might be promising. In the relative approach to expertise, more knowledgeable persons in a domain are compared with less knowledgeable persons (Chi, 2006). Thus, novices such as pre-service teachers are expected to reach the level of expertise of experts such as technology-experienced in-service teachers (Chi, 2006). This relative approach might therefore point to goals to be achieved and prerequisites to be considered when seeking to facilitate pre-service teachers' TPK-based reasoning (see Auerbach et al., 2018).

Different measures can be used to determine a person's expertise. The most prominent indicators are length of experience (also frequency of technology use in the context of digital technology; see Lee & Tsai, 2010), formal qualification or social group membership, peer assessment/social recognition and knowledge or performance tests (Chi, 2006; Palmer et al., 2005). Regarding length of experience, it might take five to seven years to reach a high level of the relevant knowledge and skills (Berliner, 2004; Palmer et al., 2005).

Empirical studies comparing pre-service teachers' to experienced in-service teachers' reasoning about teaching with technology have found differences in several ICAP-related aspects. For example, in a qualitative study, Meskill et al. (2002) compared the reasoning of in-service teachers who were experienced in using technology in the classroom with that of pre-service teachers with no such experience. They found that pre-service teachers largely saw technology as the agent that is in control of and causes learning. In contrast, experienced in-service teachers understood students as the agents of learning, and technology merely as a helpful tool. Experienced in-service teachers' technology use focused on learning activities and the associated student learning rather than the teachers themselves, their plans or merely managing students' technology use. Thus, experienced teachers tended to focus more on students' learning processes rather than products, while the reverse was true of pre-service teachers. However, this study's data were exclusively from self-report interviews, and Meskill et al. (2002) did not systematically distinguish between different types of learning activities or investigate the interplay of technology-enhanced and non-technology-enhanced activities to obtain a more complete picture of the consequences of technology-enhanced teaching in teachers' lesson planning. In addition, their data might be not representative of teachers' current teaching practices, as they were gathered almost 20 years ago.

In a more recent qualitative study, Hughes et al. (2020) interviewed pre- and in-service teachers on their most valued technologies for classroom teaching. Descriptions of the targeted student use of technology revealed that pre-service teachers mentioned passive learning activities (termed 'passive hands-off learning' by Hughes et al., 2020) more often than in-service teachers. In contrast, active learning activities (termed 'passive hands-on learning') as well as constructive and interactive learning activities (categorised as 'active hands-on learning') were reported slightly more frequently by in-service teachers compared with pre-service teachers.

Backfisch et al. (2020) confirmed these results in a study investigating differences in lesson plans created by pre-service teachers, post-graduate trainee teachers and in-service teachers in the field of mathematics. They found not only in-service teachers' but also trainee teachers' lesson plans to be of higher instructional quality (in terms of cognitive activation and instructional support) than those of pre-service teachers.

However, the samples in the studies by Hughes et al. (2020) as well as Backfisch et al. (2020) consisted of in-service teachers with high levels of general teaching experience, but not necessarily high levels of technology-enhanced teaching experience. Thus, such teachers might not actually be relative experts on teaching with technology, which could lead to erroneous conclusions regarding pre-service teachers' TPK development. Furthermore, both studies focused solely on teachers' reasoning about teaching with technology but did not examine teaching without technology. In addition, the study by Hughes et al. (2020) was characterised by a lack of standardisation in data collection, as the reasoning prompts were generic in nature and differed for pre- and in-service teachers. Consequently, only around half of the sample even addressed students' technology use. Finally, the study by Backfisch et al. (2020), although explicitly focused on lesson planning, only considered mathematics teachers and presented results on a rather abstract level ('instructional quality'), making it rather challenging to draw inferences for a broad range of teachers and concrete instructional intervention measures.

In conclusion, while these studies provide first indications for qualitative differences in teachers' reasoning about teaching with technology by relative teaching expertise, a more standardised, fine-grained quantitative and qualitative investigation of differences between technology-experienced in-service teachers' and pre-service teachers' reasoning about technology-enhanced and non-technology-enhanced learning activities is needed.

Aims and research questions

The empirical study described in this article compared pre-service teachers' and technology-experienced in-service teachers' reasoning about technology-enhanced teaching by having them develop lesson plans for an ideal technology-enhanced lesson. We investigated the technology-enhanced and non-technology-enhanced learning activities they included in a three-step mixed-methods approach based on open-ended data capturing participants' reasoning processes. First, we qualitatively analysed the data by applying coding categories derived from the ICAP framework. Second, we quantified the data in order to make statistical comparisons between pre-service teachers and technology-savvy in-service teachers (for more information on this approach, see Wecker et al., 2012). Third, we aimed to illustrate and interpret the quantitative findings and draw more fine-grained conclusions regarding how to design pre-service teacher education curricula by analysing exemplary qualitative single-case analyses.

We sought to answer the following two research questions: To what extent do pre-service teachers' and technology-experienced in-service teachers' lesson plans differ with respect to the types of learning activities they intend students to engage in (1) during technology-enhanced classroom activities and (2) during non-technology-enhanced classroom activities? Based on Meskill et al. (2002), Hughes et al. (2020) and Backfisch et al. (2020), we hypothesised that technology-experienced in-service teachers would target less passive and more active, constructive and interactive technology-enhanced learning activities than pre-service teachers (H1). As we are the first study to empirically investigate teachers' targeted use of non-technology-enhanced learning activities in the context of technology-enhanced teaching, we investigated the second research question on an explorative basis.

Method

Sample

Our sample included N = 134 pre-service and in-service teachers. The pre-service teachers were N = 99 students at a German university who fulfilled the 'novice' criterion of being in their first or second semester of studies in teacher education (semester of studies: M = 1.26, SD = 0.44). They had only limited formal learning opportunities to acquire professional (technology-related) teaching knowledge in university courses. Of the pre-service teachers, 55.6% were enrolled in a primary and 44.4% in a secondary school teacher education programme. In Germany, pre-service primary school teachers (55.6% of the total sample) as well as pre-service teachers in teacher education programmes for lower secondary school (grades 5–9; 15.2% of the total sample) are usually prepared to teach a wide range of subjects. Of the remaining 29.3% of our sample enrolled in more specialised training, 62.1% studied a language subject, 48.3% a STEM subject, 41.4% a social science subject and 10.3% an arts subject. Note that pre-service teachers were studying multiple subjects.

The technology-experienced in-service teacher group consisted of N = 35 in-service teachers who fulfilled the 'expert' criterion of a minimum of five years of professional teaching experience (a criterion suggested by Berliner, 2004; Palmer et al., 2005, as indicative of 'teacher expertise'). In addition, the technology-experienced in-service teachers were participants in a professional development programme that prepared them to work as technology-related teaching advisors in schools (48.6%), had been nominated by their peers as particularly proficient with respect to the use of digital technologies in the classroom (31.4%), were currently working as technology-related teaching advisors in schools (11.4%) or had participated in general professional development courses on teaching with technology (8.6%). Thus, this group can be characterised as having collected extensive experience with regard to the practical implementation of technology in the classroom. On average, these teachers reported having taught professionally for 11 to 15 years. Twenty per cent of technology-experienced in-service teachers taught at a primary school and 80% taught at a secondary or other school (e.g., vocational school). Again, in-service teachers in primary schools (20%) and in-service teachers in lower secondary education (28.6% of our sample) taught a wide range of school subjects. Of the remaining 51.4% of our sample, 44.4% taught a language subject, 33.3% a STEM subject, 50% a social science subject and 11.1% an arts subject. Note that teachers taught multiple subjects.

Participants were recruited in different environments: First-year pre-service teachers participated in the study as part of a psychology lecture course, which is a mandatory course for first-year pre-service teachers at the university in which the data were collected. Most of the technology-experienced in-service teachers were approached via a professional development programme for in-service teachers who were or wanted to become technology-related teaching advisors in schools. This professional development programme takes place over eight weeks spread over 2.5 years, in which in-service teachers learn about instructional, technological and legal aspects of teaching with technology. The other technology-experienced in-service teachers were approached via a university-based teacher network. Participation was voluntary.

Procedure

Participants were asked to answer a three-part online questionnaire. The first part asked for demographic data and had items testing general pedagogical knowledge (PK). In the second part, participants were asked to describe an ideal technology-enhanced lesson for a school type, subject and grade level of their choice. They were to name the lesson activities they would include and define what the teacher and what students would do during each of these activities. Participants were given the opportunity to list up to eight lesson activities. Responses to these questions were used to operationalise our dependent variables (see below). In the third part, participants were asked to answer Likert-based questions regarding their technological pedagogical knowledge (TPK) and their attitudes towards technology in the classroom. Overall, filling in the complete questionnaire took about M = 54.51 (SD = 13.05) minutes on average.

Dependent variables

We developed two coding schemes to measure the technology-enhanced and non-technology-enhanced learning activities participants included in their lesson plans. The coding schemes were applied to participants' open-ended answers with regard to the following task: 'Please draft the sequence of an ideal classroom lesson in which digital technologies are used effectively. Please describe the lesson activities and describe what the teacher and the students would do during each of these activities.' For each lesson activity, we provided participants with separate text boxes for (a) an overall description of the lesson activity, (b) a description of the teachers' action(s) during this activity and (c) a description of the students' actions during this activity. Participants were not prompted with regard to how many lesson activities they should include and how many should include the use of digital technologies.

Included types of learning activities

The first coding scheme differentiated between four types of student learning activities listed by the participants. The learning activity coding scheme consisted of four codes based on the ICAP framework (Chi & Wylie, 2014): (1) passive, (2) active, (3) constructive and (4) interactive (see Table 1). Coding examples were derived from a classroom study by Chi et al. (2018).

As participants often mentioned several learning activities within the lesson activities they outlined, two independent coders performed content segmentation of each lesson activity using the coding categories to define segments. Only learning-relevant activities performed by students were considered. Interrater agreement between two independent coders for the number of learning activities per listed lesson activity based on 36% of the data was good, ICC (2,1) = .74. The rest of the data were segmented by one coder. Thirty-three per cent of the segments were then coded by two independent coders with regard to the four different learning activities. Interrater reliability here was also sufficient, Cohen's κ = .76. The rest of the data were coded by one coder.

Technology support

The second coding scheme further differentiated the student activities mentioned by participants with respect to the degree to which they applied digital technology. The following categories were applied: (1) activities with no relation to digital technology, (2) activities enhanced with digital technology, (3) activities enhanced with both digital and non-digital technology, and (4) activities in which digital technology was the topic of discussion in the classroom (rather than actually used; see Table 2). Note that if participants mentioned activities where it was not obvious that a digital tool would be used, these activities were coded as not enhanced with digital technology.

Table 1. Coding scheme for type of learning activity.

Code	Name	*Examples*
1	Passive	*'students attentively watch a video', 'students listen to a podcast', 'students read material'*
2	Active	*'students copy notes from the blackboard', 'online search for politician', 'students have to fill in gaps'*
3	Constructive	*'each student develops quiz questions', 'drawing a schema', 'students have to compare their results to worked example'*
4	Interactive	*'students develop ideas for a project in groups', 'experiment in groups', 'students prepare a presentation in pairs'*

In applying this classification, 22% of the segments were coded by two independent coders. An acceptable Cohen's κ of .77 was achieved. The remaining segments were coded by only one coder. For further analyses, the second and third categories were collapsed, as were the first and fourth categories. Thus, only the two categories 'non-technology-enhanced' (0) and 'technology-enhanced' (1) were included in the analyses. For the statistical analyses, we also calculated the frequency of each type of technology-enhanced (TE) and non-technology-enhanced (NTE) learning activity (passive-TE, passive-NTE, active-TE, active-NTE, constructive-TE, constructive-NTE, interactive-TE, interactive-NTE) relative to the total number of learning activities.

Control variables

In order to validate the distinction we drew between pre-service teachers and technology-experienced in-service teachers, we further measured (1) participants' *general pedagogical knowledge* (PK), (2) their self-reported *technological pedagogical knowledge* (TPK) and (3) their frequency of technology use (see Lee & Tsai, 2010). To test participants' PK, items from the short version of the TEDS-M test (König & Blömeke, 2010) were used. This test assesses knowledge on relevant quality dimensions of teaching, ranging from scaffolding, motivation and assessment to diversity. Twenty-two items had a multiple-choice format (e.g., 'Which causal attribution is particularly beneficial for students' motivation?'), and two questions had an open-response format. Participants had to provide three answers to the first and four answers to the second open-response question (e.g., 'What advantages does a station rotation approach in the classroom provide?'). The open responses were coded by two independent coders based on a coding manual provided by König and Blömeke (2010). Interrater agreement was good (Cohen's κ = .79/.80). The scale's internal consistency was acceptable (Cronbach's α = .65). Participants received one point for each correct answer (Max = 29 points).

Participants' self-reported TPK was measured with four items adapted from the original scale by Schmidt et al. (2009; e.g., 'I can choose technologies that enhance students' learning in a lesson'; Cronbach's α = .62). Items were measured on a Likert-type scale from *don't agree at all* (1) to *totally agree* (5).

Finally, participants were asked to state the amount of time they spend using digital technologies each day from *0–2 hours* (1), *2–4 hours* (2), *4–6 hours* (3), *6–8 hours* (4) to *more than 8 hours* (5).

Statistical analyses

To answer our research questions, we used a MANOVA with frequency of each type of learning activity (passive-NT, active-NT, constructive-NT, interactive-NT, passive-NTE, active-NTE, constructive-NTE, interactive-NTE) as within-subject variables and group (first-year pre-service teachers vs. technology-experienced in-service teachers) as a between-subject variable. A significant MANOVA result was followed up by post-hoc univariate ANOVAs. When the assumptions of normality, equality of variances and covariance matrices were not met, we additionally performed non-parametric tests to confirm the results.

Table 2. Coding scheme for technology support.

Code	Name	*Examples*
1	No application of digital technology	*'students copy notes from the blackboard', 'teacher passes around pictures of different trees'*
2	Application of digital technology	*'teacher shows YouTube video', 'students perform an online search'*
3	Application of digital and non-digital technology	*'students can look at pictures, texts and watch videos', 'students copy a text from the whiteboard'*
4	Discussing/ talking about digital technology	*'results of an online search are presented', 'teacher scaffolds brainstorming on the topic presented in the video'*

Results

Preliminary analyses

Descriptively, technology-experienced in-service teachers had higher values of PK, TPK and frequency of technology use than first-year pre-service teachers (see Table 3). *T*-tests confirmed these differences: Technology-experienced in-service teachers had significantly higher PK scores than first-year pre-service teachers, $t(131) = 5.65$, $p < .001$, $d = 1.12$. They also reported a significantly higher TPK, $t(132) = 6.65$, $p < .001$, $d = 1.31$, and that they used technology significantly more frequently in their everyday lives, $t(132) = 3.04$, $p < .01$, $d = 0.74$, than first-year pre-service teachers. Overall, the reported results seem to warrant treating the two groups as distinguishable from one another in terms of expertise.

Group differences in learning activities

Descriptive statistics regarding the extent to which pre- and technology-experienced in-service teachers included the different types of technology-enhanced and non-technology-enhanced learning activities can be found in Table 4. First-year pre-service teachers had rather high means for passive technology-enhanced and passive non-technology-enhanced learning activities. They also noticeably targeted technology-enhanced active learning activities, while non-technology-enhanced active learning activities were much less frequent. The pre-service teachers had very low values for both technology-enhanced as well as non-technology-enhanced constructive and interactive learning activities. Passive learning activities were also the most common form of technology-enhanced learning activities among the technology-experienced in-service teachers, but to a greater extent than the pre-service teachers. The frequency of technology-enhanced active learning activities was only slightly lower than that of technology-enhanced passive learning activities. Moreover, even though in-service teachers' use of technology-enhanced constructive and interactive learning activities was rather low, it was more pronounced than that of pre-service teachers. In contrast, technology-experienced in-service teachers' pattern for non-technology-enhanced learning activities was comparable to that of pre-service teachers. The standard deviations in both groups were rather large, indicating substantial within-group differences.

A MANOVA showed a significant large effect of group on learning activities, $F(8,125) = 2.89$, $p < .01$, part. $\eta^2 = .16$, Wilk's $\Lambda = .84$. Post-hoc univariate ANOVAs further revealed that technology-experienced in-service teachers significantly less often proposed technology-enhanced passive learning activities than pre-service teachers, $F(1,132) = 6.89$, $p = .01$, part. $\eta^2 = .05$. In contrast, technology-experienced in-service teachers exhibited a significantly higher frequency of technology-enhanced constructive learning activities, $F(1,132) = 8.61$, $p < .01$, part. $\eta^2 = .06$, and interactive learning activities, $F(1,132) = 4.03$, $p = .05$, part. $\eta^2 = .03$. All other differences were not significant, all $F(1,132) < 1.34$, $p > .05$. Non-parametric tests confirmed these results (passive-TE: $U = 1203.00$, $Z = -2.71$, $p < .01$; constructive-TE: $U = 1224.50$, $Z = -3.27$, $p < .01$; interactive-TE: $U = 1434.50$, $Z = -1.98$, $p = .05$; others: $U > 1602.50$, $Z > -0.78$, $p > .05$).

Table 3. Means (*M*) and standard deviation *(SD)* for PK (Max = 29), TPK (Max = 5) and frequency of technology use (max. 5) for pre- and in-service teachers.

Variable	First-year pre-service teachers		Technology-experienced in-service teachers	
	M	*SD*	*M*	*SD*
PK	17.38	3.43	21.94	3.61
TPK	3.05	0.75	3.86	0.63
Technology use	2.41	0.88	2.97	1.07

Table 4. Means (*M*) and standard deviation (*SD*) for during technology-enhancedfrequency of targeted technology-enhanced and non-technology-enhanced learning activities for pre- and in-service teachers.

Variable	First-year pre-service teachers		Technology-experienced in-service teachers	
	M	*SD*	*M*	*SD*
Technology-enhanced learning activities	*N* = 95		*N* = 26	
Passive	0.54	0.35	0.37	0.28
Active	0.29	0.30	0.28	0.21
Constructive	0.08	0.17	0.20	0.18
Interactive	0.10	0.23	0.16	0.19
Non-technology-enhanced learning activities	*N* = 84		*N* = 27	
Passive	0.72	0.32	0.68	0.30
Active	0.16	0.26	0.16	0.27
Constructive	0.06	0.12	0.06	0.12
Interactive	0.06	0.20	0.10	0.24

Qualitative differences between pre-service teachers and technology-experienced in-service teachers

The quantitative findings demonstrated that pre-service teachers and technology-experienced in-service teachers targeted technology-enhanced learning activities to different degrees. In contrast, their pattern of non-technology-enhanced learning activities did not seem to differ on average.

In order to illustrate these findings and draw more detailed conclusions for future curricular interventions to support pre-service teachers' development of TPK, we selected lesson plans from five pre-service teachers (semester: $M = 1.40$, $SD = 0.55$) and five technology-experienced in-service teachers (median: 6–10 years of teaching experience) that exhibited the most typical patterns of learning activities in each respective group according to the quantitative findings. In other words, the selected participants had the smallest overall differences between their personal means for each learning activity variable and the respective group median for each learning activity variable. The results of our analysis are summarised in Table 5.

Surface characteristics

With regard to surface characteristics, technology-experienced in-service teachers seemed to have envisioned slightly more *learning activities* (on average 8) than pre-service teachers (on average 6). In contrast, technology-experienced in-service teachers' lesson plans were considerably briefer, containing between 75 and 210 fewer words than those of pre-service teachers, which contained

Table 5. Characteristics of lesson plans by five pre-service teachers and five in-service teachers.

<table>
<tr><th>Categories</th><th>First-year pre-service teachers</th><th>Technology-experienced in-service teachers</th></tr>
<tr><td>Surface characteristics</td><td>6 learning activities
75–210 words
Content specific</td><td>8 learning activities
199–304 words
Content independent</td></tr>
<tr><td></td><td colspan="2">Moderate technology use</td></tr>
<tr><td>Passive learning activities</td><td colspan="2">Introductory classroom activities</td></tr>
<tr><td></td><td></td><td>Student presentations (TE)</td></tr>
<tr><td></td><td colspan="2">Transmission of information (TE)</td></tr>
<tr><td></td><td colspan="2">Open-ended whole-class activities (NTE)</td></tr>
<tr><td>Active learning activities</td><td colspan="2">Quizzes (TE)</td></tr>
<tr><td></td><td>Taking notes (TE, NTE)</td><td>Online search (TE)</td></tr>
<tr><td>Constructive learning activities</td><td></td><td>Preparation of digital presentations (TE)</td></tr>
<tr><td>Interactive learning activities</td><td></td><td>Creation of products (TE)</td></tr>
<tr><td>Further characteristics</td><td>Teachers as managers</td><td>Teachers as learning guides</td></tr>
<tr><td></td><td colspan="2">Standard technologies</td></tr>
</table>

Note. TE = technology-enhanced; NTE = non-technology-enhanced.

between 199 and 304 words except for one lesson plan with 63 words (in the original language). A reason for this variation might be found in another characteristic in which the pre- and in-service teachers' lesson plans differed: While four in-service teachers (IST1, IST2, IST3, IST5) out of the five in-service teachers' lesson plans did not refer to any specific *content*, but rather seemed to represent a more general lesson description applicable to various topics, most of the pre-service teachers' (PST1, PST2, PST3, PST4) lesson plans were more specific about and adapted to the topic to be taught. Thus, the in-service teachers' ideal lesson plans demonstrate a more abstract internal cognitive script (Fischer et al., 2013) for a technology-enhanced lesson, which they have acquired based on their extensive experience and might function as a general structure to be filled with content. In comparison, pre-service teachers might have simply referred to concrete lesson examples they have already experienced and/or built a lesson from scratch.

The *proportion of technology-enhanced learning activities* was around two-thirds in both groups, indicating a moderate level of technology use, which seems preferable to heavy technology use with respect to students' learning outcomes according to existing empirical research (R. F. Schmid et al., 2014). However, as mentioned earlier, the kind of technology or learning activities implemented seem to be of greater importance for students' learning.

Passive learning activities

In terms of deep structure, passive learning activities were most frequent in both pre-service teachers' as well as technology-experienced in-service teachers' lesson plans. Nevertheless, the in-service teachers included technology-enhanced passive learning activities less often than pre-service teachers.

Qualitatively, we further noticed that passive learning activities were most frequently included as an *introductory classroom activity* by both pre-service teachers and in-service teachers (except for PST2 and IST5). However, while the majority of pre-service teachers explicitly mentioned videos as a medium (e.g., PST1, PST2, PST4), most technology-experienced in-service teachers spoke merely of a stimulus, leaving the intended medium open (abstract internal script; IST1, IST2, IST3). Moreover, both pre- and in-service teachers also included passive learning activities in the remainder of the described classroom activities, mostly in the form of *whole-class activities*. These activities are generally understood as passive learning activities (see Chi & Wylie, 2014) since only a relatively small number of students are engaged in a non-passive type of learning activity.

However, pre- and in-service teachers differed regarding the kind of technology-enhanced passive learning activities they included. Three of the in-service teachers' lesson plans involved technology-enhanced *student presentations* in the context of an individual or group activity focused on researching and working through content material (IST1, IST2, IST3). Interestingly, IST2 saw potential to enrich the student presentations by including an online quiz created by the students in their groups. Thus, the in-service teachers' passive learning activities at least integrate the passive learning mode with higher-quality modes of learning activities, ranging from active to interactive (e.g., a group activity). The pre-service teachers' lesson plans only mentioned technology-enhanced student presentations once (PST4). Their lesson plans were instead characterised by the *technology-enhanced transmission* of information (PST2: teacher presentation; PST3: video). However, the in-service teachers' lesson plans also exhibited transmission features (IST3: teacher presentation, IST5: video).

The pre- and in-service teachers do not seem to differ much concerning non-technology-enhanced passive learning activities. A typical pattern seems to emerge in both pre- and in-service teachers' lesson plans, as non-technology enhanced passive learning activities in both groups mostly consisted of *open-ended, less structured whole-class activities* such as brainstorming (IST2), reflection (IST1) and discussion (PST2, PST4) formats. Again, this type of activities is classified as passive since only a relatively small number of students are engaged in a non-passive type of learning activity. Consequently, teachers seem to see technology's potential for more clearly defined passive learning activities rather than for more open passive whole-class learning formats.

Active learning activities

Active learning activities were the second most-mentioned type of learning activities by both pre- and in-service teachers. This was true for both technology-enhanced and non-technology-enhanced learning activities, even though technology-enhanced active learning activities were much more common than non-technology-enhanced passive learning activities.

With regard to technology-enhanced active learning activities, *quizzes* were frequently mentioned in both groups (PST3, PST4, IST2, IST3, IST4). It seems that this format enjoys great popularity irrespective of technology-enhanced teaching experience. Apart from that, pre-service teachers were also rather inclined to have students *take notes* on the presented content, which concerned not only technology-enhanced learning activities (PST2: taking notes on a video; PST5: copying content presented via digital projector), but also non-technology-enhanced learning activities (PST2, PST3: copying notes from a blackboard). A common feature of technology-experienced in-service teachers' ideal lesson plans was to have students perform *online searches for information* (IST1, IST2, IST3). Thus, overall, it seems that pre-service teachers tended to opt for more teacher-guided, highly structured active learning activities, whereas in-service teachers more frequently proposed more student-regulated active learning activities. The latter can be considered more promising with regard to students' acquisition of twenty-first-century skills (Partnership for 21st Century Learning, 2019), as long as teachers provide adequate support (Lazonder & Harmsen, 2016; see also the section on further characteristics).

Constructive learning activities

The quantitative results showed that both pre- and in-service teachers seldom mentioned constructive learning activities. However, technology-experienced in-service teachers referred to technology-enhanced constructive learning activities more often than pre-service teachers.

In line with these results, a technology-enhanced constructive learning activity was only mentioned once by a pre-service teacher (PST4: creating a mind map). In contrast, three out of the five in-service teachers (IST1, IST2, IST5) described technology-enhanced constructive learning activities, while two even included two constructive activities each (IST1: summarising material, preparing a presentation; IST2: preparing a presentation, developing quiz questions). What these two lesson plans had in common was having students prepare *digital presentations* (see also the section on passive learning activities).

Furthermore, it was striking that none of the selected pre- and in-service teachers included *any purely non-technology-enhanced constructive learning activities*. Thus, it seems that in technology-enhanced classrooms, digital tools might be increasingly superseding paper-and-pencil formats when it comes to engaging students in the development of learning products.

Interactive learning activities

The quantitative results for interactive learning activities are comparable to those for constructive learning activities. Both technology-enhanced and non-technology-enhanced learning activities of this type were mentioned least often by both pre- and in-service teachers, although technology-enhanced interactive learning activities were more common in in-service teachers' lesson plans than pre-service teachers' lesson plans.

Once again, only one pre-service teacher (PST2) mentioned an interactive (technology-enhanced) learning activity, making it rather difficult to draw comparisons between pre- and in-service teachers with regard to the nature of these activities. Nevertheless, while PST2 only envisioned having students *compare their results*, the activities mentioned by the three in-service teachers (IST3, IST4, IST5) again seemed to be more open-ended and creative challenges, as they involved having students *create a product together* (IST3: presentation, IST4: quiz questions, IST5: dialogue). Similar to constructive learning activities, all of the interactive learning activities mentioned (with the exception of one in-service teacher (IST5) were technology enhanced. However, technology served as an information resource (PST2, IST4) or as a means of creating a learning product (IST3, IST4) rather than to support students' collaboration (see also section on further characteristics).

Further characteristics

Alongside the differences and commonalities between pre- and in-service teachers' lessons plans just described, two other characteristics seem worth noting.

First, while our analysis primarily focused on student activities, we also uncovered differences between pre- and in-service teachers regarding the envisioned *teacher activities*. In most of the pre-service teachers' lesson plans, the anticipated role of the teacher seemed to be to instruct students in the sense of providing students with content and/or tasks to complete. This was particularly apparent when digital tools came into play (e.g., PST1: 'teacher can give his students the opportunity to dive more deeply into the topic via computer learning games'; PST2: 'teacher withdraws and listens to the presentations'; PST4: 'teacher can share a link to a quiz'). Given the pre-service teachers' failure to further elaborate on teacher behaviour during such activities, one might assume that these pre-service teachers do not see the need for any teacher action, as the tool 'takes over'. In contrast, in-service teachers were more likely to specify teacher actions and stress the teacher's role as a learning guide who supports students during their engagement in technology-enhanced learning activities (e.g., IST1: 'support in case of problems'; IST2: 'teacher assists students as they work on their presentations', 'teacher gives advice on how to collect information'; IST3: 'supporting the presentations').

A second characteristic of the lesson plans we noted was rather similar between pre- and in-service teachers' lesson plans, namely the *types of technology envisioned*. Contrary to expectations, we did not observe that technology-experienced in-service teachers use different, more innovative or more diverse technology in the classroom than pre-service teachers. Even technology-experienced teachers' lesson plans primarily employed rather basic digital tools such as presentation software, search engines, quiz software, and digital content such as videos or images. However, there are many more possibilities for employing technology in instruction, particularly when it comes to constructive and interactive learning activities.

Discussion

Digital technology is attributed great potential to improve students' learning in schools. In order to exploit this potential, it is essential that pre-service teachers acquire TPACK in order to effectively promote learning activities that are associated with a deep understanding of the subject matter. We argue that future curricular interventions aiming to successfully support pre-service teachers' TPACK development should consider empirical evidence on technology-experienced in-service teachers' TPACK as a possible target state. In doing so, and in accordance with suggestions to adapt the TPACK framework to twenty-first-century learning, we suggested drawing upon the learner-centred ICAP model by Chi and Wylie (2014), as it defines different observable learning activities and possible relations to students' learning outcomes. Consequently, in this study, we investigated TPK in the form of ideal lesson plans reported by first-year pre-service teachers and technology-experienced in-service teachers and identified differences in the types of technology-enhanced and non-technology -enhanced learning activities included. Our quantitative and qualitative results only partially confirmed the hypothesised differences between pre- and in-service teachers. In this section, we elaborate on the results in more detail.

Regarding the effect of technology-related teaching expertise on technology-enhanced learning activities (RQ1), we found that technology-experienced in-service teachers envision significantly fewer passive and significantly more constructive and interactive learning activities than pre-service teachers. Consequently, our findings only partially confirm our hypothesis as well as prior research on teaching experience (Backfisch et al., 2020; Hughes et al., 2020; Meskill et al., 2002) and its positive effects on teachers' cognitive and behavioural processes. While Hughes et al. (2020) found that in-service teachers also more strongly focus on active learning activities, this was not the case in our study. Nevertheless, this finding may not come as a surprise when considering the different contextual characteristics of the study of Hughes et al. (2020) and our study (e.g., the different samples, see also theoretical background).

That being said, it seems that in-service teachers have collected experiences indicating that student engagement in higher-level technology-enhanced learning activities is associated with better learning, and thus seem to direct their attention to promoting such activities via technology. The qualitative analyses particularly point to a large number of more open-ended, student-regulated activities among in-service teachers. In contrast, pre-service teachers have less knowledge and experience with technology's learning potential than technology-experienced in-service teachers and seem to be more focused on the technology itself than on students' learning processes. This became especially apparent in the qualitative analyses. The observation that pre-service teachers' lesson plans envision teachers as managers and in-service teachers' lesson plans envision teachers as learning guides aligns well with Meskill et al. (2002), who found that technology-experienced in-service teachers in contrast to pre-service teachers understand students rather than technology as the agents of learning and focus more on the learning process than learning products.

However, with regard to the second research question, the descriptive differences between pre- and in-service teachers' use of non-technology-enhanced learning activities were rather small and non-significant. One might assume that expertise in teaching with technology encompasses largely context-specific experiences and knowledge and may thus not be easily transferable to non-technology-enhanced activities (see domain specificity of expertise; Ericsson & Lehmann, 1996). On the other hand, technology-experienced in-service teachers might also aim for a balance of different types of technology-enhanced and non-technology-enhanced learning activities. While the in-service teachers envisioned various learning activities WITH technological support, they mostly included passive learning activities WITHOUT technological support. This leads to an open question upon which the ICAP model (Chi & Wylie, 2014) is silent: What would an ideal implementation and balance of learning activities look like in classrooms? To what degree is it necessary to intersperse a lesson with at least some passive and active learning activities when tackling a new domain or topic? These questions could be interesting research avenues for future studies.

Nevertheless, based on the qualitative comparisons of pre-service teachers' and technology-experienced in-service teachers' ideal lesson plans and the included technology-enhanced learning activities, we suggest that efforts to facilitate pre-service teachers' TPK development should particularly encourage pre-service teachers to consider open-ended, student-regulated activities as productive technology-enhanced learning activities. For example, several in-service teachers suggested having students prepare student products on a particular topic. This kind of approach targets twenty-first-century skills ranging from creative thinking, collaborating and communicating with others to accessing, evaluating and using information, creating media products and self-directed working (Partnership for 21st Century Learning, 2015). However, the in-service teachers' lesson plans also indicate that when providing students with such challenging tasks, it is also necessary for pre-service teachers to understand teachers' role as learning guides, who not only present materials or tasks, but also support students in their technology-enhanced learning process (Kollar et al., 2011). This kind of support probably will not be accomplished by technology itself in the near future.

Limitations and conclusion

Several limitations must be addressed which might diminish the explanatory power of the study. First, even though we tested for knowledge-relevant differences between groups, the sample of teachers might have been biased. Thus, we recommend assessing components beyond PK, TPK and frequency of technology use to further assess to what extent pre-service teachers and in-service teachers differ from each other and to potentially identify key variables beyond teaching experience that may contribute to the differences we found in our study.

Furthermore, data on learning activities were only analysed on the level of lesson plans. Such an approach that only prompts teachers to describe a set of activities might not represent a constructivist methodology itself and might have led teachers to understand teaching with technology as a rather fixed sequence of activities that can be applied to all kinds of teaching situations. In turn, associations with actual teaching practices can only be assumed, as teachers' reasoning in lesson plans might overestimate their actual TPK in practice (Heitink et al., 2017, 2016). Thus, while teachers' reasoning in the form of their lesson plans can illustrate the potential of the envisioned learning activities for actual teaching, it should not be equivalated with actual teaching. Future studies should thus also consider teachers' reasoning about the kinds of students' learning processes that might be associated with certain teaching activities and investigate real-life teaching situations involving the use of digital technologies.

Finally, it should be noted that the ICAP model has been subject to criticism (e.g., Renkl, 2015). The assumption that visible learning activities can be directly associated with cognitive processes is regarded as problematic. Moreover, empirical results from other research fields such as learning with worked examples show that seemingly passive learning activities might in some instances be more effective than more 'active' types of learning activities (Renkl, 2015). Nevertheless, the fact that we found differences between first-year pre-service teachers and technology-experienced in-service teachers in the extent to which they envisioned employing the different activities proposed by Chi (2009) lends some validity to (at least) the assumptions about the significance of certain learning activities for student learning.

Despite these shortcomings, this study of pre- and in-service teachers' envisioned learning activities was helpful in revealing potential targets for curricular interventions to support pre-service teachers' TPK development. It seems necessary to help pre-service teachers effectively use the potential of digital technologies to evoke certain constructive and interactive learning activities and related cognitive processes. One promising approach to achieve this aim is to scaffold pre-service teachers' pedagogical reasoning skills or professional vision skills (noticing and knowledge-based reasoning processes) by having them analyse videos of actual teachers and students interacting with digital technology in the classroom (e.g., Seidel et al., 2013) based on empirically grounded models such as the ICAP model. However, such a knowledge-based intervention approach should be further enhanced by addressing students' positive attitudes towards passive learning activities (see U. Schmid et al., 2017). We therefore suggest considering models such as the technology acceptance model (e.g., Venkatesh & Bala, 2008), which point the way to increasing pre-service teachers' acceptance of more innovative digital technologies that afford constructive and interactive learning activities by having pre-service teachers experience their usability and potential value for stimulating deep learning processes. This could support teachers' development of effective technology-enhanced teaching scenarios, which in turn may lead them to modify their teaching practices.

Acknowledgments

We would like to thank Tugce Özbek for her support in coding the data.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by Bundesministerium für Bildung und Forschung [grant number 01JA1509].

Notes on contributors

Christina Wekerle obtained a Master's degree in Educational Sciences, Psychology and Intercultural Communication at LMU Munich (2006–12). She is currently a research assistant at the Chair of Educational Psychology at the University of Augsburg. Since 2021, she is the project coordinator of the project 'Facilitating Competence Development through Authentic, Digital and Feedback-Based Teaching-Learning Scenarios' at the University of Augsburg.

Ingo Kollar obtained a Master's degree in Educational Science, Psychology and Sociology at LMU Munich. He has a doctoral degree in Psychology from Eberhard-Karls-Universität Tübingen (2006). He is currently Full Professor for Educational Psychology at the University of Augsburg.

ORCID

Christina Wekerle http://orcid.org/0000-0002-4622-999X
Ingo Kollar http://orcid.org/0000-0001-9257-5028

References

Angeli, C., & Valanides, N. (2009). Epistemological and methodological issues for the conceptualization, development, and assessment of ICT–TPCK: Advances in technological pedagogical content knowledge (TPCK). *Computers & Education*, *52*(1), 154–168. https://doi.org/10.1016/j.compedu.2008.07.006

Auerbach, A. J., Higgins, M., Brickman, P., Andrews, T. C. (2018). Teacher knowledge for active-learning instruction: Expert-novice comparison reveals differences. *CBE Life Sciences Education*, *17*(1), ar12. https://doi.org/10.1187/cbe.17-07-0149

Backfisch, I., Lachner, A., Hische, C., Loose, F., & Scheiter, K. (2020). Professional knowledge or motivation? Investigating the role of teachers' expertise on the quality of technology-enhanced lesson plans. *Learning and Instruction*, *66*, 101300. https://doi.org/10.1016/j.learninstruc.2019.101300

Berliner, D. C. (2004). Describing the behavior and documenting the accomplishments of expert teachers. *Bulletin of Science, Technology & Society*, *24*(3), 200–212. https://doi.org/10.1177/0270467604265535

Brantley-Dias, L., & Ertmer, P. A. (2013). Goldilocks and TPACK. Is the construct 'just right? *Journal of Research on Technology in Education*, *46*(2), 103–128. https://doi.org/10.1080/15391523.2013.10782615

Castillo-Manzano, J. I., Castro-Nuño, M., López-Valpuesta, L., Sanz-Díaz, M. T., & Yñiguez, R. (2016). Measuring the effect of ARS on academic performance: A global meta-analysis. *Computers & Education*, *96*, 109–121. https://doi.org/10.1016/j.compedu.2016.02.007

Chai, C. S., Koh, J. H. L., & Tsai, C.-C. (2013). A review of technological pedagogical content knowledge. *Educational Technology & Society*, *16*(2), 31–51. https://www.jstor.org/stable/10.2307/jeductechsoci.16.2.31

Chauhan, S. (2017). A meta-analysis of the impact of technology on learning effectiveness of elementary students. *Computers & Education*, *105*, 14–30. https://doi.org/10.1016/j.compedu.2016.11.005

Cheung, A. C. K., & Slavin, R. E. (2013). The effectiveness of educational technology applications for enhancing mathematics achievement in K–12 classrooms: A meta-analysis. *Educational Research Review*, *9*, 88–113. http://dx.doi.org/10.1016/j.edurev.2013.01.001

Chi, M. T. (2006). Two approaches to the study of experts' characteristics. In K. Ericsson, N. Charness, P. Feltovich, & R. Hoffman (Eds.), *The Cambridge handbook of expertise and expert performance* (pp. 21–30). Cambridge Handbooks in Psychology. Cambridge University Press.

Chi, M. T. (2009). Active-constructive-interactive: A conceptual framework for differentiating learning activities. *Topics in Cognitive Science*, *1*(1), 73–105. https://doi.org/10.1111/j.1756-8765.2008.01005.x

Chi, M. T., & Wylie, R. (2014). The ICAP framework: Linking cognitive engagement to active learning outcomes. *Educational Psychologist*, *49*(4), 219–243. https://doi.org/10.1080/00461520.2014.965823

Chi, M. T. H., Adams, J., Bogusch, E. B., Bruchok, C., Kang, S., Lancaster, M., Levy, R., Li, N., McEldoon, K. L., Stump, G. S., Wylie, R., Xu, D., & Yaghmourian, D. L. (2018). Translating the ICAP theory of cognitive engagement into practice. *Cognitive Science*, *42*(6), 1777–1832. https://doi.org/10.1111/cogs.12626

Chien, Y.-T., Chang, Y.-H., & Chang, C.-Y. (2016). Do we click in the right way? A meta-analytic review of clicker-integrated instruction. *Educational Research Review*, *17*, 1–18. https://doi.org/10.1016/j.edurev.2015.10.003

Ericsson, K. A., & Lehmann, A. C. (1996). Expert and exceptional performance: Evidence of maximal adaptation to task constraints. *Annual Review of Psychology*, *47*(1), 273–305. https://doi.org/10.1146/annurev.psych.47.1.273

Fischer, F., Kollar, I., Stegmann, K., & Wecker, C. (2013). Toward a script theory of guidance in computer-supported collaborative learning. *Educational Psychologist*, *48*(1), 56–66. https://doi.org/10.1080/00461520.2012.748005

Harris, J., Grandgenett, N., & Hofer, M. J. (2010). Testing a TPACK-based technology integration assessment rubric. In C. D. Maddux, D. Gibson, & B. Dodge (Eds.), *Research highlights in technology and teacher education 2010 [E-reader version]* (pp. 323–331). Society for Information Technology and Teacher Education. http://publish.wm.edu/bookchapters/6

Heitink, M., Voogt, J., Verplanken, L., van Braak, J., & Fisser, P. (2016). Teachers' professional reasoning about their pedagogical use of technology. *Computers & Education*, *101*, 70–83. https://doi.org/10.1016/j.compedu.2016.05.009

Heitink, M., Voogt, J., Fisser, P., Verplanken, L., & van Braak, J. (2017). Eliciting teachers' technological pedagogical knowledge. *Australasian Journal of Educational Technology*, *33*(3), 96–109. https://doi.org/10.14742/ajet.3505

Hughes, J. E., Cheah, Y. H., Shi, Y., & Hsiao, K.-H. (2020). Preservice and inservice teachers' pedagogical reasoning underlying their most-valued technology-supported instructional activities. *Journal of Computer Assisted Learning*, *36*(4), 549–568. https://doi.org/10.1111/jcal.12425

Janssen, J., & Bodemer, D. (2013). Coordinated computer-supported collaborative learning: Awareness and awareness tools. *Educational Psychologist*, *48*(1), 40–55. https://doi.org/10.1080/00461520.2012.749153

Koehler, M. J., & Mishra, P. (2009). What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education*, *9*(1), 60–70. https://www.learntechlib.org/primary/p/29544/

Koh, J. H. L., Chai, C. S., & Lim, W. Y. (2017). Teacher professional development for TPACK-21CL: Effects on teacher ICT integration and student outcomes. *Journal of Educational Computing Research*, *55*(2), 172–196. https://doi.org/10.1177/0735633116656848

Kollar, I., Wecker, C., Langer, S., & Fischer, F. (2011). Orchestrating web-based collaborative inquiry learning with small group and classroom scripts. In H. Spada, G. Stahl, N. Miyake, & N. Law (Eds.), *Connecting computer-supported collaborative learning to policy and practice: CSCL2011 conference proceedings, volume 1 – long papers* (pp. 422–429). International Society of the Learning Sciences. https://repository.isls.org/bitstream/1/2479/1/422-429.pdf

König, J., & Blömeke, S. (2010). *Pädagogisches Unterrichtswissen: Dokumentation der Kurzfassung des TEDS-M-Testinstruments zur Kompetenzmessung in der ersten Phase der Lehrerausbildung [General pedagogical knowledge: Documentation of the short version of the TEDS-M test instrument for competence measurement in the first phase of teacher education]*. Humboldt-Universität.

Law, N., & Chow, A. (2008). Teacher characteristics, contextual factors, and how these affect the pedagogical use of ICT. In N. Law & T. Plomp (Eds.), *Pedagogy and ICT use* (pp. 181–219). Springer.

Lazonder, A. W., & Harmsen, R. (2016). Meta-analysis of inquiry-based learning. *Review of Educational Research*, *86*(3), 681–718. https://doi.org/10.3102/0034654315627366

Lee, M.-H., & Tsai, C.-C. (2010). Exploring teachers' perceived self efficacy and technological pedagogical content knowledge with respect to educational use of the world wide web. *Instructional Science*, *38*(1), 1–21. https://doi.org/10.1007/s11251-008-9075-4

Menekse, M., Stump, G. S., Krause, S., & Chi, M. T. (2013). Differentiated overt learning activities for effective instruction in engineering classrooms. *Journal of Engineering Education*, *102*(3), 346–374. https://doi.org/10.1002/jee.20021

Meskill, C., Mossop, J., DiAngelo, S., & Pasquale, R. K. (2002). Expert and novice teachers talking technology: Precepts, concepts, and misconcepts. *Language Learning & Technology*, *6*(3), 46–57. https://doi.org/10.125/25176

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, *108*(6), 1017–1054. https://www.learntechlib.org/p/99246/

Olofson, M. W., Swallow, M. J. C., & Neumann, M. D. (2016). TPACKing: A constructivist framing of TPACK to analyze teachers' construction of knowledge. *Computers & Education*, *95*, 188–201. https://doi.org/10.1016/j.compedu.2015.12.010

Palmer, D. J., Stough, L. M., Burdenski, J. T. K., & Gonzales, M. (2005). Identifying teacher expertise: An examination of researchers' decision making. *Educational Psychologist*, *40*(1), 13–25. https://doi.org/10.1207/s15326985ep4001_2

Partnership for 21st Century Learning. (2015). *P21 framework definitions*. http://static.ba ttelleforkids.org/documents/p21/P21_Framework_Definitions_New_Logo_2015_9pgs.pdf

Partnership for 21st Century Learning. (2019). *Framework for 21st century learning: A unified vision for learning to ensure student success in a world where change is constant and learning never stops*. http://static.battelleforkids.org/documents/p21/P21_Framework_Brief.pdf

Renkl, A. (2015). Different roads lead to Rome: The case of principle-based cognitive skills. *Learning: Research and Practice*, *1*(1), 79–90. https://doi.org/10.1080/23735082.2015.994255

Scherer, R., Tondeur, J., & Siddiq, F. (2017). On the quest for validity: Testing the factor structure and measurement invariance of the technology-dimensions in the Technological, Pedagogical, and Content Knowledge (TPACK) model. *Computers & Education*, *112*, 1–17. https://doi.org/10.1016/j.compedu.2017.04.012

Schmid, R. F., Bernard, R. M., Borokhovski, E., Tamim, R. M., Abrami, P. C., Surkes, M. A., Wade, C. A., & Woods, J. (2014). The effects of technology use in postsecondary education: A meta-analysis of classroom applications. *Computers & Education*, *72*, 271–291. https://doi.org/10.1016/j.compedu.2013.11.002

Schmid, U., Goertz, L., Radomski, S., Thom, S., & Behrens, J. (2017). *Monitor Digitale Bildung: Die Hochschulen im digitalen Zeitalter [Monitor digital education: Universities in the digital age]*. Bertelsmann Stiftung. https://www.bertelsmann-stiftung.de/fileadmin/files/BSt/Publikationen/GrauePublikationen/DigiMonitor_Hochschulen_final.pdf

Schmidt, D. A., Baran, E., Thompson, A. D., Mishra, P., Koehler, M. J., & Shin, T. S. (2009). Technological pedagogical content knowledge (TPACK): The development and validation of an assessment instrument for preservice teachers. *Journal of Research on Technology in Education*, *42*(2), 123–149. https://doi.org/10.1080/15391523.2009.10782544

Seidel, T., Prenzel, M., Duit, R., Euler, M., Geiser, H., Hoffmann, L., Lehrke, M., Müller, C. T., & Rimmle, R. (2002). Jetzt bitte alle nach vorne schauen!" – Lehr-Lernskripts im Physikunterricht und damit verbundene Bedingungen für individuelle Lernprozesse ["Please look ahead now!" – Teaching and learning scripts in physics instruction and related prerequisites for individual learning processes]. *Unterrichtswissenschaft*, *30*(1), 52–77.

Seidel, T., Blomberg, G., & Renkl, A. (2013). Instructional strategies for using video in teacher education. *Teaching and Teacher Education*, *34*(1), 56–65. https://doi.org/10.1016/j.tate.2013.03.004

Shulman, L. S. (1986). Paradigms and research programs in the study of teaching: A contemporary perspective. In M. C. Wittrock (Ed.), *Handbook of research on teaching* (pp. 3–35). Macmillan.

Standing Conference of the Ministers of Education and Cultural Affairs. (2019). *Standards für die Lehrerbildung: Bildungswissenschaften* [Standards for teacher education: Educational sciences]. https://www.kmk.org/fileadmin/veroeffentlichungen_beschluesse/2004/2004_12_16-Standards-Lehrerbildung-Bildungswissenschaften.pdf

Sung, Y.-T., Chang, K.-E., & Liu, T.-C. (2016). The effects of integrating mobile devices with teaching and learning on students' learning performance: A meta-analysis and research synthesis. *Computers & Education*, *94*, 252–275. http://doi.org/10.1016/j.compedu.2015.11.008

Tamim, R. M., Bernard, R. M., Borokhovski, E., Abrami, P. C., & Schmid, R. F. (2011). What forty years of research says about the impact of technology on learning: A second-order meta-analysis and validation study. *Review of Educational Research*, *81*(1), 4–28. https://doi.org/10.3102/0034654310393361

U.S. Department of Education. (2016). *Advancing educational technology in teacher preparation: Policy brief*. https://tech.ed.gov/files/2016/12/Ed-Tech-in-Teacher-Preparation-Brief.pdf

Venkatesh, V., & Bala, H. (2008). Technology Acceptance Model 3 and a research agenda on interventions. *Decision Sciences*, *39*(2), 273–315. https://doi.org/10.1111/j.1540-5915.2008.00192.x

Voogt, J., Fisser, P., Tondeur, J., & van Braak, J. (2016). Using theoretical perspectives in developing an understanding of TPACK. In M. Herring, M. J. Koehler, & P. Mishra (Eds.), *Handbook of technological pedagogical content knowledge (TPACK) for educators* (2nd ed., pp. 33–51). Routledge.

Wecker, C., Stegmann, K., & Fischer, F. (2012). Lern- und Kooperationsprozesse: Warum sind sie interessant und wie können sie analysiert werden? [Learning and collaboration processes: Why are they interesting and how can we analyse them?] REPORT. *Zeitschrift für Weiterbildungsforschung*, *35*(3), 30–41. https://doi.org/10.3278/REP1203W030

Willermark, S. (2018). Technological pedagogical and content knowledge: A review of empirical studies published from 2011 to 2016. *Journal of Educational Computing Research*, *56*(3), 315–343. https://doi.org/10.1177/0735633117713114