



Full length article

Technology-related knowledge, skills, and attitudes of pre- and in-service teachers: The current situation and emerging trends

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ABSTRACT

This is the introductory article for the special issue “Technology-related knowledge, skills, and attitudes of pre- and in-service teachers”. It (1) specifies the concept of technology-related knowledge, skills, and attitudes (KSA) of teachers, (2) presents how these KSA are currently assessed, and (3) outlines ways of fostering them among pre- and in-service teachers. The eight articles in the special issue are structured accordingly, and we demonstrate how they contribute to knowledge in these three areas. Moreover, we show how the afterword to the special issue widens the perspective on technology integration by taking into account systems and cultures of practice. Due to their quantitative empirical nature, the eight articles investigate technology at the current state of the art. However, the potential of artificial intelligence has not yet been fully exploited in education. We provide an outlook on potential developments and their implications on teachers’ technology-related KSA. To this end, we introduce the concept of augmentation strategies.

1. Introduction

“Emergency remote teaching” has become a worldwide phenomenon due to COVID-19, resulting in a temporary shift to online teaching (Hodges, Moore, Lockee, Trust, & Bond, 2020). These exceptional circumstances have brought the use of technology in education to the attention of a broader public. The term (educational) technology frequently refers implicitly to digital technology. For instance, Tamim, Bernard, Borokhovski, Abrami, and Schmid (2011) include in their second-order meta-analysis about technology “computer technology as a supplement for in-class instruction” (p. 7). The recent meta-analysis of J-PAL (2019), which aims at a comprehensive overview of educational technology, classified four groups: 1) access to technology, e.g., computers and internet access, 2) computer assisted learning, e.g., educational software, 3) technology-enabled behavioral interventions, e.g., gamification, and 4) online learning, e.g., massive open online courses. Regular claims are that (advanced) educational technology will improve learning efficiency, facilitate greater focus on the future professional needs of learners, and foster personality development in a digital society. However, such claims are often based on ‘myths’ instead of sound

research (Kirschner & van Merriënboer, 2013). The meta-analysis of J-PAL (2019)¹ based on evidence from experimental research indicates that the use of technology can lead to positive but not overwhelming effects on learning outcomes. This is in line with the study by Tamim et al. (2011) that condensed forty years of research about technology in education. It reveals average effect sizes between 0.30 and 0.35 (depending on the method used). Both studies reveal a substantial variance among effect sizes, which may indicate that it is not meaningful to talk about technology in general terms. In this vein, the fact that technology use in empirical studies is often of short duration should also be considered. It is questionable whether conditions developed for an experimental design of short duration can be sustained in normal classroom settings (Cheung & Slavin, 2013). Moreover, technology is a very dynamic concept (Koehler, Mishra, & Cain, 2013) and more recent technology may yield higher learning outcomes. In summary, there seems to be some potential for the use of technology in terms of improving educational processes. However, the effectiveness and efficiency of such technology (not surprisingly) depends on the way it is used, which could point to an important role for teachers.

Indeed, the available evidence may indicate an important role of

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teachers in the integration of technology into education (Fraillon, Ainley, Schulz, Friedman, & Duckworth, 2019; OECD, 2015). In this vein, Dillenbourg (2013) coined the term *orchestration*. Teachers have to manage multiple activities while considering multiple constraints. They have to decide in which context they use or do not use a specific technology. Such decision-making processes may be guided by findings about high-quality learning environments (e.g., Merrill, 2002). As Sweller (2020, p. 1) posited: “Technology-based instruction used without reference to the instructional design principles that flow from human cognition is likely to be random in its effectiveness.” To deliberately use technology, teachers need specific knowledge, skills, and attitudes (KSA) (Kirschner, 2015).

In this introductory article for the special issue “Technology-related knowledge, skills, and attitudes of pre- and in-service teachers”, we specify the concept of technology-related knowledge, skills, and attitudes (KSA) of teachers (section 2.1 and 2.2), present how these KSA are currently assessed (section 2.3), and outline ways of fostering them among pre- and in-service teachers (section 2.4). Section 3 explains how the eight articles in this special issue contribute to the knowledge base in these three areas. Section 4 provides an outlook on how technology-related KSA might change in the future due to new technological developments, especially artificial intelligence.

2. Technology-related KSA

2.1. Knowledge and skills

Successful problem solvers possess well-organized and flexible reservoirs of knowledge that they can apply within various contexts (Ericsson & Lehmann, 1996). Drawing on the work of Shulman (1986; 1987), Park and Oliver (2008) identified in their literature review four communalities of teachers’ professional knowledge: pedagogical knowledge (PK), content knowledge (CK), pedagogical content knowledge (PCK), and knowledge of context. Mishra and Koehler (2006) added technological knowledge (TK) as a further type (Koehler & Mishra, 2009; Mishra & Koehler, 2006). Their so-called TPACK framework (see Fig. 1) has gained broad attention among researchers (Harris, Phillips, Koehler, & Rosenberg, 2017; Hew, Lan, Tang, Jia, & Lo, 2019;

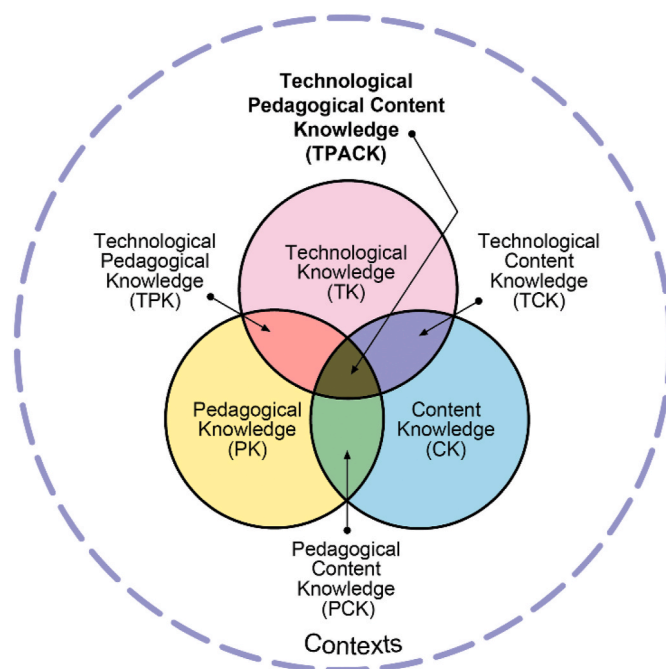


Fig. 1. TPACK framework. Reproduced by permission of the publisher © 2012 by tpack.org.

Petko, 2020; Saubern, Henderson, Heinrich, & Redmond, 2020; Voogt, Fisser, Pareja Roblin, Tondeur, & van Braak, 2013); most of the contributions to this special issue use it as a theoretical background. The core that emerges from interaction between CK, PK, and TK (Koehler et al., 2013) is TPACK (see Fig. 1).

As the name implies, TPACK may refer to knowledge; however, researchers also conceptualized the components of the TPACK framework as skills (i.e., the application of knowledge) or competence (Willermark, 2018). For a discussion on this, see Sailer et al. (2020, this issue) and Wekerle and Kollar (2020, this issue).

Although the TPACK framework is well-established, it has been challenged (Angeli & Valanides, 2009; Graham, 2011): The building blocks PK, CK, and TK are insufficiently (theoretically) conceptualized. In particular, it often remains unclear what kind of technology TK comprises. The range could be broad, e.g., from chalk boards to social robots. Besides the underlying constructs themselves, their relationship with each other is an issue (Petko, 2020). This relationship could be integrative or transformative. The integrative view implies that all constructs directly contribute to TPACK, e.g., an increase in TK directly yields an increase in TPACK. The transformative view posits that the influence of CK, PK, and TK on TPACK is fully mediated by TPK, TCK, and PCK (see Fig. 1). Based on a sample of pre-service teachers, Schmid, Brianza, and Petko (2020) recently provided evidence in favor of the transformative view. However, using a sample of in-service teachers, the findings of Koh, Chai, and Tsai (2013) may, in part, point to an integrative view because TK and PK are directly associated with TPACK. A further criticism of the TPACK framework is its ability to predict meaningful outcomes (Graham, 2011). Available studies in general refer to (self-reported) use (Farjon, Smits, & Voogt, 2019; Guggemos & Seufert, 2020, this issue; Schmid, Brianza, & Petko, 2020, this issue). However, in the end, the desired outcome would be gains in student learning. In other contexts, studies that rely on student learning are available. For instance, Baumert et al. (2010) showed in a longitudinal study that the objectively measured PCK of teachers can explain class variance in mathematics achievement reasonably well ($R^2 = 39\%$).

2.2. Attitudes

Besides professional knowledge and skills, teachers’ attitudes, especially the beliefs that form such attitudes (Instefjord & Munthe, 2017), have received much attention. Empirical evidence lends support to the important role of beliefs in the process of technology integration (Cheng & Xie, 2018; Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur, & Sendurur, 2012; Petko, 2012; Tondeur, van Braak, Ertmer, & Ottenbreit-Leftwich, 2017). Unsurprisingly, attitudes also play an important role in predicting the adoption of technology by teachers. Following the theory of planned behavior (Ajzen, 1991), the attitude towards a behavior is one of three predictors for behavioral intention. Moreover, the will, skill, tool model implies attitudes are a predictor for the actual use of technology (Knezek & Christensen, 2016). Indeed, Scherer and Teo (2019) identified in their meta-analysis attitudes as a significant predictor for teachers’ intention to use technology; however, they did not consider the actual use, which might be problematic (Nistor, 2014). Scherer, Tondeur, Siddiq, and Baran (2018) showed that attitudes towards technology can be an important predictor for the level of TPACK in pre-service teachers.

2.3. Assessment of technology-related KSA

Quantitative research about technology integration depends on instruments to measure the constructs of interest; the validity of the findings heavily depends on the quality of the used instruments. Moreover, for professional development, instruments are necessary to identify potentials for improvement (formative assessment). In general, assessment instruments in the realm of teachers’ technology-related KSA can be separated into self-assessment and external (objective)

instruments (Kaplon-Schilis & Lyublinskaya, 2020). Although the use of self-assessment instruments has been challenged (Lachner, Backfisch, & Stürmer, 2019), they are regularly used to capture technology-related KSA. Various self-assessment instruments are available (e.g., Schmid et al., 2020; Valtonen et al., 2017; for an overview see Voogt et al., 2013). Generally speaking, self-assessments may not be inferior to objective measures (Conway & Lance, 2010). Rather, the validity of an assessment can only be evaluated with respect to its purpose (AERA, APA, & NCME, 2014). Scherer, Tondeur, and Siddiq (2017) pointed out five advantages of self-assessment instruments. First, they are a cost-efficient, reliable, and valid indicator for teachers' self-efficacy beliefs. Second, they are important predictors for teachers' intention to use technology. Third, they are geared towards future behavior. Fourth, self-efficacy beliefs correlate with the quality of instruction and favorable educational outcomes. Fifth, self-efficacy beliefs are a desirable outcome of the education and professional development of teachers. In summary, self-reports and objective measures might capture different constructs (self-efficacy beliefs vs. performance) that are both important; hence, they may be regarded as complementary (Drummond & Sweeney, 2017).

For a valid assessment, both curriculum and instruction have to be taken into account (Pellegriano, DiBello, & Goldman, 2016). The curriculum specifies the kind of knowledge (pre-service) teachers are expected to possess. Hence, if teachers' technology-related KSA are to be assessed, the pertinent standards have to be considered. For instance, Tondeur, Aesaert, et al. (2017) reviewed various standards to develop an instrument to measure the technological skills of pre-service teachers. Sailer et al. (2020, this issue) and Rubach et al. (2020, this issue) also considered the pertinent curricula for developing self-assessment instruments. Such an approach, where the facets that constitute technology-related knowledge or skills are clearly pointed out, may also be conducive for identifying potential aspects of professional development. Besides the necessity for clearly specifying the constructs' structure, proficiency levels stating at what level teachers are expected to possess these technology-related KSA are important. To form such proficiency levels, Saubern, Urbach, Koehler, and Phillips (2020) relied on item response theory and developed a model of teachers' TPACK confidence that comprises five levels. By means of such proficiency levels, the results of an assessment can be interpreted by referring to clearly specified criteria.

Currently, there seems to be much room for improvement in the practice of assessment (Petko, 2020). To move forwards, it may be helpful to consider research about assessing the professional development of teachers in general, e.g., Blömeke and Delaney (2012). For PK, Voss, Kunter, and Baumert (2011) developed a model comprising five facets, e.g., classroom management. As Nistor (2014) argued in the realm of technology acceptance, it may be necessary to consider in a better manner the complexity and dimensionality of the underlying constructs. Such a claim might be in line with Saubern et al. (2020, p. 6) who stated it may be important "to understand the knowledge that teachers need to use technology effectively for teaching and learning", i. e., what are the building blocks that constitute technology-related knowledge. Following the call for more elaborate instruments, Rubach et al. (2020, this issue), for instance, use a six-dimensional model to develop a self-assessment instrument that measures TK. To form proficiency levels, the approach of Hartig, Frey, Nold, and Klieme (2012) may be helpful.

2.4. Fostering technology-related knowledge, skills, and attitudes

Adopting technology for learning purposes is a complex endeavor (Straub, 2009). We cannot expect prospective teachers to possess technology-related knowledge and skills simply because they grew up with digital technology (for more on the myth of digital natives, see Kirschner & Bruyckere, 2017). Rather, training and professional development might be necessary. Based on a systematic review of qualitative

studies, Tondeur et al. (2012) developed a Synthesis of Qualitative Evidence (SQD) model for preparing pre-service teachers to include technology in their classroom practices. They identified six themes on the micro level concerning the preparation of pre-service teachers. A questionnaire that operationalizes these six themes is available (Tondeur, van Braak, Siddiq, & Scherer, 2016). Moreover, there is evidence for a positive association between the perceived occurrence of the SQD strategies and TPACK (Tondeur, Scherer, Siddiq, & Baran, 2020). Table 1 summarizes the themes of the SQD model.

The SQD model may not only be helpful for training pre-service teachers, but also for professional development in general. Yurtseven Avcı, O'Dwyer, and Lawson (2020) reviewed thirty-two studies about professional development in the realm of technology in education. Overall, they identified categories that are consistent with the SQD model. For instance, they suggest that skilled teachers with a highly positive attitude towards technology could act as coaches or mentors to support their colleagues. What might be specific to in-service teachers could be learning communities or communities of practice that play an important role in the professional development of teachers (Lawless & Pellegrino, 2007; Tseng & Kuo, 2014).

3. Contributions in this special issue

3.1. Overview

The eight articles and the afterword in this special issue aim at fostering a better understanding of the technology-related KSA of pre- and in-service teachers; Table 2 provides an overview.

3.2. Specifying technology-related KSA

Guggemos and Seufert (2020, this issue) use the TPACK framework as the theoretical background to predict teachers' use of technology as a means and as the content of instruction (teaching with and about technology). They rely on structural equation modeling to test their hypotheses. For the critical conceptualization of 'technology', they utilized the DigComp 2.1 framework of the European Union (Carretero, Vuorikari, & Punie, 2017). Moreover, they consider a new type of knowledge—technological collaboration knowledge (TCoK). Interaction and collaboration is important in knowledge acquisition in general (Chi & Wylie, 2014) and especially so in the professional development of teachers (Vangrieken, Meredith, Packer, & Kyndt, 2017). However, collaboration is seldom taken into account in TPACK research. Most available studies that rely on the TPACK framework do not consider the collaborative aspect. By integrating TCoK, Guggemos and Seufert (2020, this issue) may be in line with Petko (2020), who argues that for theory development, the TPACK framework could be extended without changing its core.

Hämäläinen et al. (2020, this issue) utilize data from large-scale studies (PIAAC and TALIS) and conduct secondary analyses. The

Table 1
Micro-level themes of the SQD model.

Theme	Manifestation in teacher training
Role model	Pedagogical meaningful use of technology is embedded in all kinds of activities, e.g., in lectures and seminars
Reflection	Reflection and discussion on the use of technology is an integral part
Instructional design	Students receive help in preparing lessons that include technology
Collaboration	Students have opportunities to work together with fellow students, supporting each other, and sharing experiences
Authentic experiences	Students receive opportunities to test themselves using technology in the classroom (in internships)
Feedback	Students receive feedback about their use of technology and about further improvements

Note. The SQD model as presented by Tondeur et al. (2012; 2016).

Table 2
Overview of the contributions.

No.	Authors	Context	Sample size
Specifying technology-related KSA			
1	Guggemos and Seufert	In-service, Switzerland, VET schools	212
2	Hämäläinen, Nissinen, Taajamo, and Lämsä	In-service, 14 countries, various school levels	67,102
3	Valtonen, Hoang, Sointu, Näykki, Mäkitalo, Kukkonen, Virtanen, Järvelä, and Häkkinen	Pre-service, Finland, high schools, three-wave longitudinal	704
Assessing technology-related KSA			
4	Schmid, Brianza, and Petko	Pre-service, Switzerland, middle schools	173
5	Sailer, Stadler, Schultz-Pernice, Franke, Schöffmann, Paniotova, Husagic, and Fischer	Pre- and in-service, Germany, primary and high schools	90
6	Rubach, Lazarides, and Quast	In-service, Germany, primary and high schools	449
Fostering technology-related KSA			
7	Wekerle and Kollar	Pre-service, Germany, high schools	252
8	Tondeur, Howard, and Yang	Pre-service, Belgium, high schools	931
Afterword			
9	Mishra and Warr	conceptual	n/a

authors take advantage of the very large sample sizes of these studies and investigate to what extent teachers possess technology-related KSA. Personal and contextual factors are considered as well. While there is notable variance in teachers' knowledge and skills, their attitudes show less variance as they generally recognize the importance of teaching with digital technologies. However, despite the fact that teachers, in general, seem to recognize the importance of technology use, some teachers do not rate digital skills as very important for their work. On one hand, there is a group of teaching professionals which believes their digital skills are adequate and this group does indeed have advanced digital skills. On the other, another group of teaching professionals believes their skills are adequate for their work but teachers from this group have a poor grasp of digital skills. Based on their findings, the authors present implications for professional development.

In general, technology-related KSA can be embedded within the wider context of 21st-century skills (Kirschner & Stoyanov, 2020; van Laar, van Deursen, van Dijk, & Haan, 2017; Voogt & Roblin, 2012). In a similar vein, Valtonen et al. (2020, this issue) investigated the development of 21st-century skills of pre-service teachers at three Finnish universities using latent growth curve modeling. The TPACK framework and the theory of planned behavior acts as the theoretical background for operationalizing technology-related knowledge and self-efficacy. Such longitudinal designs may be important for obtaining a better understanding of developmental processes (Petko, 2020). Interestingly, TPK and technology self-efficacy showed significant growth, whereas other 21st-century skills, such as negotiation or team leadership, remained rather stable over the three-year time frame.

3.3. Assessing technology-related KSA

Schmid, Brianza, and Petko (2020, this issue) address an important question in TPACK research, namely, the validity of self-assessments. To this end, they investigate how those constructs (see Fig. 1) measured with self-assessment instruments relate to planned technology use in lessons. To capture the planned technology use, pre-service teachers were asked to design a lesson for a topic of their choice; no explicit prompt for including the use of technology was given. Moreover, the authors carry out a cluster analysis to identify TPACK profiles among the pre-service teachers in their sample that could predict planned technology use in lessons. In this vein, they distinguish between use of technology by the teacher and use of technology by the students.

However, neither the constructs of the TPACK framework nor the identified profiles in the cluster analysis are associated with technology use in lessons. The authors discuss these remarkable findings.

Sailer et al. (2020, this issue) present and validate by means of confirmatory factor analysis a self-assessment instrument for teachers' technology-related skills and attitudes. Their work goes beyond available assessment instruments in many ways. First, they use scenarios to make the type and circumstances of technology use clear to test takers. Second, they address skills, whereas many studies focus on knowledge. Third, they take pertinent curricula into account and consider instructional practices, which may contribute to the validity of the instrument (Pellegrino et al., 2016). Fourth, they consider the use of technology across all kinds of teaching activities, e.g., planning and evaluating, instead of solely teaching in the classroom. Fifth, when validating their instrument, they not only take the frequency but also the kind of technology use into account (Chi & Wylie, 2014). The developed instrument is freely available.

Rubach, Lazarides, and Quast (2020, this issue) also present and validate by means of confirmatory factor analysis a self-assessment instrument. The construct of interest is ICT competence beliefs, which may be regarded as TK based on the TPACK framework. In line with the call for more elaborate instruments, they rely on a six-dimensional model that is based on pertinent standards, e.g., DigComp (Ferrari, 2013). The facets are 'Information and data literacy', 'Communication and collaboration', 'Digital content creation', 'Safety and security', 'Problem solving', and 'Analyzing and reflecting'. The authors provide evidence for the structure of their model, as well as for convergent and discriminant validity. The validated instrument is part of the article.

3.4. Fostering technology-related KSA

In line with the call of Petko (2020) for more rigor in research designs, Wekerle and Kollar (2020, this issue) utilize an experimental design and objective measures. The TPACK framework acts as the theoretical background. However, instead of knowledge they focus on situation-specific skills (Blömeke, Gustafsson, & Shavelson, 2015) in the form of professional vision. In their 2 × 2 between-subjects design they vary the factor mapping (reading vs. mapping) and worked examples (problem solving vs. worked examples). The students read three texts covering PK-related content. In the mapping conditions students were further instructed to create a combined mind map. They then worked with written cases of classroom lessons that included technology-enhanced teacher and student actions. They either received worked examples on how to reason regarding these cases and were prompted to explain them (worked examples), or they were asked to reason with these cases without further instruction (problem solving). Wekerle and Kollar conclude by suggesting that learning by mapping, if carried out properly, might have a positive influence on declarative knowledge. Students who studied worked examples (instead of solving problems) showed better noticing, explanation, and solution skills.

As described in section 2.4, the SQD is a model for training pre-service teachers. Tondeur et al. (2020, this issue) aim at increasing the usefulness of this model. To this end, they utilize association rules analysis as a data mining technique (García, Romero, Ventura, & Castro, 2011). Here, rules are formulated as if-then statements, e.g., if A and B, then C and D. Each rule includes at least one antecedent (A) and one consequent (C). In the case of Tondeur et al. the rules are formed based on answers to an SQD questionnaire. Furthermore, they distinguished between teachers with negative and positive attitudes towards technology. They found remarkably different association patterns. Pre-service teachers with negative attitudes showed an emphasis on feedback, and students with positive attitudes towards collaboration. This different structure of associations could be regarded as further evidence for the important role of attitudes towards technology for understanding technology integration. Moreover, the authors discuss the implications for more personalized training of pre-service teachers.

3.5. Afterword

The contributions in this special issue are found on the micro-level, i. e., the focus is on individual teachers. In the afterword, *Mishra and Parr* (2020, this issue) widen the perspective. For an in-depth understanding of technology integration, they argue that specific systems and cultures of practice have to be considered. With this in mind, they present the five spaces framework. This model might also reveal promising avenues for further research which may contribute to a better understanding of technology integration.

4. Outlook

In terms of digitalization, it may be helpful to differentiate between two waves (*Wahlster, 2017*). The first wave has been driven by the digitization of data and the internet. The studies in this special issue are (due to their quantitative empirical nature) part of the first wave. The second wave is characterized by technologies like artificial intelligence (AI), which focus on understanding data in order to utilize them for various purposes. In education, the potential of AI has not been fully exploited (*Luckin, Holmes, Griffiths, & Forcier, 2016*). Recent publications and major international funding schemes point to the perceived importance of AI in education (*Hasse, Cortesi, Lombana, & Gasser, 2019; Lytras, Sarirete, & Damiani, 2020; Stanford University, 2016; Yueh & Chiang, 2020*). Concerning the role of AI in education, *Holmes, Bialik, and Fadel (2019)* pointed to a crucial point: “Whether we welcome it or not, AI is increasingly being used widely across education and learning contexts. We can either leave it to others—the computer scientists, AI engineers and big tech companies—to decide how artificial intelligence in education unfolds, or we can ... adopt a critical stance, to help ensure that the introduction of AI into education reaches its potential and has positive outcomes for all.” (*Holmes et al., 2019, p. 179*).

For a better understanding of the impact of AI on professionals in education, e.g., teachers, the concept of *augmentation strategies* by *Davenport and Kirby (2016)* could be helpful. This generic framework describes how the relationship between humans and smart machines (driven by AI) might unfold in the future. In the following section, we will point out what augmentation strategies could evolve in education. On the one hand, new specialized skill profiles may be needed (e.g., educational data scientists, the ‘step in’ strategy) and, on the other hand, the skill profiles of existing roles in teaching and learning might change (e.g., smart machines support teachers during instruction, the ‘step aside’ strategy). Moreover, a ‘step forward’ strategy is possible (e.g., contributing to the development of AI-based learning solutions). A ‘step up’ strategy is especially important for education and school managers. It deals with important questions of data protection and the use of student data in an ethical way because, as with every technology, AI also poses dangers. “[We] are excited by what AI has to offer teaching and learning ... but we are also very cautious. We have seen an extraordinary range of AIED approaches ... and some amazing future AIED possibilities ... However, we have also identified a range of critical issues that need to be addressed before AI becomes an acceptable integral part of everyday learning.” (*Holmes et al., 2019, p. 179*).

The augmentation strategies show how the role of professionals in education could look like within the context of a second wave of digitalization, as well as which KSA might be necessary depending on the pursued strategy. However, the question that remains is how can such a transformation process be integrated into the daily business of schools? In organization theory, ambidexterity, as a so-called two-handed leadership approach, has long been a much noticed concept (*O’Reilly & Tushman, 2008*). It addresses the ability to exploit existing opportunities (left hand) while at the same time exploring new ones (right hand). Accompanied by this is the question of how exploitation (optimizing the existing) and exploration (exploring the new) can be integrated into an organization such as a school. Principals and teachers are currently faced with the challenge of integrating exploration alongside

their everyday business (exploitation). There is a risk that investments made today in certain digital skills will be outdated in five years’ time. New interactions between human beings and smart machines raise new fundamental questions that cannot yet be answered comprehensively by the education and professional development of teachers. Therefore, it might be useful to better understand and further investigate the concept of augmented work and augmentation strategies for the teaching profession in order to identify the technology-related KSA of teachers (*Seufert, Guggemos, & Sonderegger, 2020*).

The second wave of digitalization does not mean that less teachers are needed (*Dillenbourg, 2016*). Human expectations towards smart machines are certainly less sensitive than those towards human teachers. The augmented work of the teaching profession has to be researched, as well as how teachers might engage with smart machines within their teaching environment. *Dillenbourg (2013)* argues for the orchestration of learning—the real-time management of classroom activities—across the classroom ecosystem. In the future, this orchestration process could include smart machines.

The direction of thought has been deliberately redirected: not always planning the next few years based on the current situation but, conversely, designing scenarios for the future and, from this perspective, exploring possible areas of development on how learning and teaching in schools might look in the future. Teachers should be enabled and supported to sit in the driver seat in order to shape their schools during this current major transitional phase—to quote *Kay’s (1971)* well-known remark: “The best way to predict the future is to invent it.”

CRedit authorship contribution statement

Sabine Seufert: Conceptualization, Writing - original draft, Writing - review & editing, Supervision. **Josef Guggemos:** Conceptualization, Writing - original draft, Writing - review & editing, Project administration. **Michael Sailer:** Conceptualization, Writing - original draft, Writing - review & editing, Project administration.

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References

- AERA, A. P. A., & NCME. (2014). *Standards for educational and psychological testing*. American Educational Research Association.
- Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, 50(2), 179–211. [https://doi.org/10.1016/0749-5978\(91\)90020-T](https://doi.org/10.1016/0749-5978(91)90020-T)
- 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>
- Baumert, J., Kunter, M., Blum, W., Brunner, M., Voss, T., Jordan, A., & Tsai, Y.-M. (2010). Teachers’ mathematical knowledge, cognitive activation in the classroom, and student progress. *American Educational Research Journal*, 47(1), 133–180. <https://doi.org/10.3102/0002831209345157>
- Blömeke, S., & Delaney, S. (2012). Assessment of teacher knowledge across countries: A review of the state of research. *ZDM*, 44(3), 223–247. <https://doi.org/10.1007/s11858-012-0429-7>
- Blömeke, S., Gustafsson, J.-E., & Shavelson, R. J. (2015). Beyond dichotomies. *Zeitschrift für Psychologie*, 223(1), 3–13. <https://doi.org/10.1027/2151-2604/a000194>
- Carretero, S., Vuorikari, R., & Punie, Y. (2017). *DigComp 2.1: The Digital Competence Framework for Citizens with eight proficiency levels and examples of use*. Luxembourg: European Union (EU). <https://doi.org/10.2760/38842>
- Cheng, S.-L., & Xie, K. (2018). The relations among teacher value beliefs, personal characteristics, and TPACK in intervention and non-intervention settings. *Teaching and Teacher Education*, 74, 98–113. <https://doi.org/10.1016/j.tate.2018.04.014>
- 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. <https://doi.org/10.1016/j.edurev.2013.01.001>

- Chi, M. T. H., & 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>
- Conway, J. M., & Lance, C. E. (2010). What reviewers should expect from authors regarding common method bias in organizational research. *Journal of Business and Psychology*, 25(3), 325–334. <https://doi.org/10.1007/s10869-010-9181-6>
- Davenport, T. H., & Kirby, J. (2016). *Only humans need apply: Winners and losers in the age of smart machines*. Harper Business.
- Dillenbourg, P. (2013). Design for classroom orchestration. *Computers & Education*, 69, 485–492. <https://doi.org/10.1016/j.compedu.2013.04.013>
- Dillenbourg, P. (2016). The evolution of research on digital education. *International Journal of Artificial Intelligence in Education*, 26(2), 544–560. <https://doi.org/10.1007/s40593-016-0106-z>
- Drummond, A., & Sweeney, T. (2017). Can an objective measure of technological pedagogical content knowledge (TPACK) supplement existing TPACK measures? *British Journal of Educational Technology*, 48(4), 928–939. <https://doi.org/10.1111/bjet.12473>
- Ericsson, K. A., & Lehmann, A. C. (1996). Expert and exceptional performance: Evidence of maximal adaptation to task constraints. *Annual Review of Psychology*, 47, 273–305. <https://doi.org/10.1146/annurev.psych.47.1.273>
- Ertmer, P. A., Ottenbreit-Leftwich, A. T., Sadik, O., Sendurur, E., & Sendurur, P. (2012). Teacher beliefs and technology integration practices: A critical relationship. *Computers & Education*, 59(2), 423–435. <https://doi.org/10.1016/j.compedu.2012.02.001>
- Farjon, D., Smits, A., & Voogt, J. M. (2019). Technology integration of pre-service teachers explained by attitudes and beliefs, competency, access, and experience. *Computers & Education*, 130, 81–93. <https://doi.org/10.1016/j.compedu.2018.11.010>
- Ferrari, A. (2013). *Digcomp: A framework for developing and understanding digital competence in europe*. Publications Office.
- Fraillon, J., Ainley, J., Schulz, W., Friedman, T., & Duckworth, D. (2019). *Preparing for life in a digital world: IEA international computer and information literacy study 2018 international report*. Amsterdam: International Association for the Evaluation of Educational Achievement (IEA). <https://www.iea.nl/publications/study-reports/preparing-life-digital-world>
- García, E., Romero, C., Ventura, S., & Castro, C. de (2011). A collaborative educational association rule mining tool. *The Internet and Higher Education*, 14(2), 77–88. <https://doi.org/10.1016/j.iheduc.2010.07.006>
- Graham, C. R. (2011). Theoretical considerations for understanding technological pedagogical content knowledge (TPACK). *Computers & Education*, 57(3), 1953–1960. <https://doi.org/10.1016/j.compedu.2011.04.010>
- Harris, J. B., Phillips, M., Koehler, M. J., & Rosenberg, J. M. (2017). TPACK/TPACK research and development: Past, present, and future directions. *Australasian Journal of Educational Technology*, 33(3). <https://doi.org/10.14742/ajet.3907>
- Hartig, J., Frey, A., Nold, G., & Klieme, E. (2012). An application of explanatory item response modeling for model-based proficiency scaling. *Educational and Psychological Measurement*, 72(4), 665–686. <https://doi.org/10.1177/0013164411430707>
- Hasse, A., Cortesi, S. C., Lombana, A., & Gasser, U. (2019). Youth and artificial intelligence: Where we stand. In *SSRN electronic journal*. Advance online publication. <https://doi.org/10.2139/ssrn.3385718>
- Hew, K. F., Lan, M., Tang, Y., Jia, C., & Lo, C. K. (2019). Where is the “theory” within the field of educational technology research? *British Journal of Educational Technology*, 50(3), 956–971. <https://doi.org/10.1111/bjet.12770>
- Hodges, C., Moore, S., Locke, B., Trust, T., & Bond, A. (2020). *The difference between emergency remote teaching and online learning*. <https://medicine.hofstra.edu/pdf/faculty/facdev/facdev-article.pdf>
- Holmes, W., Bialik, M., & Fadel, C. (2019). *Artificial intelligence in education: Promises and implications for teaching and learning*. The Center for Curriculum Redesign.
- Instefjord, E. J., & Munthe, E. (2017). Educating digitally competent teachers: A study of integration of professional digital competence in teacher education. *Teaching and Teacher Education*, 67, 37–45. <https://doi.org/10.1016/j.tate.2017.05.016>
- J-PAL. (2019). *Will technology transform education for the better?*. <https://www.povertyactionlab.org/publication/will-technology-transform-education-better>
- Kaplon-Schilis, A., & Lyublinskaya, I. (2020). Analysis of relationship between five domains of TPACK framework: TK, PK, CK math, CK science, and TPACK of pre-service special education teachers. *Technology, Knowledge and Learning*, 25(1), 25–43. <https://doi.org/10.1007/s10758-019-09404-x>
- Kay, A. (1971). *The best way to predict the future is to invent it*. https://en.wikiquote.org/wiki/Alan_Kay
- Kirschner, P. A. (2015). Do we need teachers as designers of technology enhanced learning? *Instructional Science*, 43(2), 309–322. <https://doi.org/10.1007/s11251-015-9346-9>
- Kirschner, P. A., & Bruyckere, P. de (2017). The myths of the digital native and the multitasker. *Teaching and Teacher Education*, 67, 135–142. <https://doi.org/10.1016/j.tate.2017.06.001>
- Kirschner, P. A., & Stoyanov, S. (2020). Educating youth for nonexistent/not yet existing professions. *Educational Policy*, 34(3), 477–517. <https://doi.org/10.1177/0895904818802086>
- Kirschner, P. A., & van Merriënboer, J. J. G. (2013). Do learners really know best? Urban legends in education. *Educational Psychologist*, 48(3), 169–183. <https://doi.org/10.1080/00461520.2013.804395>
- Knezek, G., & Christensen, R. (2016). Extending the will, skill, tool model of technology integration: Adding pedagogy as a new model construct. *Journal of Computing in Higher Education*, 28(3), 307–325. <https://doi.org/10.1007/s12528-016-9120-2>
- Koehler, M. J., & Mishra, P. (2009). What is technological pedagogical content knowledge? *Contemporary Issues in Technology and Teacher Education*, 9(1), 60–70.
- Koehler, M. J., Mishra, P., & Cain, W. (2013). What is technological pedagogical content knowledge (TPACK)? *Journal of Education*, 193(3), 13–19. <https://doi.org/10.1177/002205741319300303>
- Koh, J. H. L., Chai, C. S., & Tsai, C.-C. (2013). Examining practicing teachers’ perceptions of technological pedagogical content knowledge (TPACK) pathways: A structural equation modeling approach. *Instructional Science*, 41(4), 793–809. <https://doi.org/10.1007/s11251-012-9249-y>
- Lachner, A., Backfisch, I., & Stürmer, K. (2019). A test-based approach of modeling and measuring Technological Pedagogical Knowledge. *Computers & Education*, 142, 103645. <https://doi.org/10.1016/j.compedu.2019.103645>
- Lawless, K. A., & Pellegrino, J. W. (2007). Professional development in integrating technology into teaching and learning: Knowns, unknowns, and ways to pursue better questions and answers. *Review of Educational Research*, 77(4), 575–614. <https://doi.org/10.3102/0034654307309921>
- Luckin, R., Holmes, W., Griffiths, M., & Forcier, L. B. (2016). *Intelligence unleashed: An argument for AI in education*. Pearson Education.
- Lytras, M., Sarirete, A., & Damiani, E. (2020). Technology-enhanced learning research in higher education: A transformative education primer. *Computers in Human Behavior*, 109, 106350. <https://doi.org/10.1016/j.chb.2020.106350>
- Merrill, M. D. (2002). First principles of instruction. *Educational Technology Research & Development*, 50(3), 43–59. <https://doi.org/10.1007/BF02505024>
- Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, 108(6), 1017–1054.
- Nistor, N. (2014). When technology acceptance models won’t work: Non-significant intention-behavior effects. *Computers in Human Behavior*, 34, 299–300. <https://doi.org/10.1016/j.chb.2014.02.052>
- OECD. (2015). *Students, computers and learning*. Advance online publication. <https://doi.org/10.1787/9789264239555-en>
- O’Reilly, C. A., & Tushman, M. L. (2008). Ambidexterity as a dynamic capability: Resolving the innovator’s dilemma. *Research in Organizational Behavior*, 28, 185–206. <https://doi.org/10.1016/J.RIOB.2008.06.002>
- Park, S., & Oliver, J. S. (2008). Revisiting the conceptualisation of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in Science Education*, 38(3), 261–284. <https://doi.org/10.1007/s11165-007-9049-6>
- Pellegrino, J. W., DiBello, L. V., & Goldman, S. R. (2016). A Framework for conceptualizing and evaluating the validity of instructionally relevant assessments. *Educational Psychologist*, 51(1), 59–81. <https://doi.org/10.1080/00461520.2016.1145550>
- Petko, D. (2012). Teachers’ pedagogical beliefs and their use of digital media in classrooms: Sharpening the focus of the ‘will, skill, tool’ model and integrating teachers’ constructivist orientations. *Computers & Education*, 58(4), 1351–1359. <https://doi.org/10.1016/j.compedu.2011.12.013>
- Petko, D. (2020). Quo vadis TPACK? Scouting the road ahead. *EdMedia + Innovate Learning*, 23, 1277–1286.
- Saubern, R., Henderson, M., Heinrich, E., & Redmond, P. (2020). Tpack – time to reboot? *Australasian Journal of Educational Technology*, 36(3), 1–9. <https://doi.org/10.14742/ajet.6378>
- Saubern, R., Urbach, D., Koehler, M., & Phillips, M. (2020). Describing increasing proficiency in teachers’ knowledge of the effective use of digital technology. *Computers & Education*, 147, 103784. <https://doi.org/10.1016/j.compedu.2019.103784>
- Scherer, R., & Teo, T. (2019). Unpacking teachers’ intentions to integrate technology: A meta-analysis. *Educational Research Review*, 27, 90–109. <https://doi.org/10.1016/j.edurev.2019.03.001>
- 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>
- Scherer, R., Tondeur, J., Siddiq, F., & Baran, E. (2018). The importance of attitudes toward technology for pre-service teachers’ technological, pedagogical, and content knowledge: Comparing structural equation modeling approaches. *Computers in Human Behavior*, 80, 67–80. <https://doi.org/10.1016/j.chb.2017.11.003>
- Schmid, M., Brianza, E., & Petko, D. (2020). Developing a short assessment instrument for Technological Pedagogical Content Knowledge (TPACK.xs) and comparing the factor structure of an integrative and a transformative model. *Computers & Education*, 157, 103967. <https://doi.org/10.1016/j.compedu.2020.103967>
- Seufert, S., Guggemos, J., & Sonderegger, S. (2020). Digitale Transformation der Hochschullehre: Augmentationsstrategien für den Einsatz von Data Analytics und Künstlicher Intelligenz [Digital transformation in higher education: Augmentation strategies for the use of data analytics and artificial intelligence]. *ZfHE*, 15(1), 81–101. <https://doi.org/10.3217/zfhe-15-01/05>
- Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, 15(2), 4–14. <https://doi.org/10.3102/0013189X015002004>
- Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review*, 57(1), 1–23. <https://doi.org/10.17763/haer.57.1.j463w79r56455411>
- Stanford University. (2016). *Artificial intelligence and life in 2030. One hundred year study on artificial intelligence: Report of the 2015-2016 study panel*. Author https://ai100.stanford.edu/sites/g/files/sbiybj9861/ai_100_report_0831fnl.pdf
- Straub, E. T. (2009). Understanding technology adoption: Theory and future directions for informal learning. *Review of Educational Research*, 79(2), 625–649. <https://doi.org/10.3102/0034654308325896>
- Sweller, J. (2020). Cognitive load theory and educational technology. *Educational Technology Research & Development*, 68(1), 1–16. <https://doi.org/10.1007/s11423-019-09701-3>

- 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. *Review of Educational Research*, 81(1), 4–28. <https://doi.org/10.3102/0034654310393361>
- Tondeur, J., Aesaert, K., Pynoo, B., van Braak, J., Fraeyman, N., & Erstad, O. (2017). Developing a validated instrument to measure preservice teachers' ICT competencies: Meeting the demands of the 21st century. *British Journal of Educational Technology*, 48(2), 462–472. <https://doi.org/10.1111/bjet.12380>
- Tondeur, J., Scherer, R., Siddiq, F., & Baran, E. (2020). Enhancing pre-service teachers' technological pedagogical content knowledge (TPACK): A mixed-method study. *Educational Technology Research & Development*, 68(1), 319–343. <https://doi.org/10.1007/s11423-019-09692-1>
- Tondeur, J., van Braak, J., Ertmer, P. A., & Ottenbreit-Leftwich, A. (2017). Understanding the relationship between teachers' pedagogical beliefs and technology use in education: A systematic review of qualitative evidence. *Educational Technology Research & Development*, 65(3), 555–575. <https://doi.org/10.1007/s11423-016-9481-2>
- Tondeur, J., van Braak, J., Sang, G., Voogt, J. M., Fisser, P., & Ottenbreit-Leftwich, A. (2012). Preparing pre-service teachers to integrate technology in education: A synthesis of qualitative evidence. *Computers & Education*, 59(1), 134–144. <https://doi.org/10.1016/j.compedu.2011.10.009>
- Tondeur, J., van Braak, J., Siddiq, F., & Scherer, R. (2016). Time for a new approach to prepare future teachers for educational technology use: Its meaning and measurement. *Computers & Education*, 94, 134–150. <https://doi.org/10.1016/j.compedu.2015.11.009>
- Tseng, F.-C., & Kuo, F.-Y. (2014). A study of social participation and knowledge sharing in the teachers' online professional community of practice. *Computers & Education*, 72, 37–47. <https://doi.org/10.1016/j.compedu.2013.10.005>
- Valtonen, T., Sointu, E., Kukkonen, J., Kontkanen, S., Lambert, M. C., & Mäkitalo-Siegl, K. (2017). TPACK updated to measure pre-service teachers' twenty-first century skills. *Australasian Journal of Educational Technology*, 33(3). <https://doi.org/10.14742/ajet.3518>
- Van Laar, E., van Deursen, A. J. A. M., van Dijk, J. A. G. M., & Haan, J. de (2017). The relation between 21st-century skills and digital skills: A systematic literature review. *Computers in Human Behavior*, 72, 577–588. <https://doi.org/10.1016/j.chb.2017.03.010>
- Vangrieken, K., Meredith, C., Packer, T., & Kyndt, E. (2017). Teacher communities as a context for professional development: A systematic review. *Teaching and Teacher Education*, 61, 47–59. <https://doi.org/10.1016/j.tate.2016.10.001>
- Voogt, J. M., Fisser, P., Pareja Roblin, N., Tondeur, J., & van Braak, J. (2013). Technological pedagogical content knowledge - a review of the literature. *Journal of Computer Assisted Learning*, 29(2), 109–121. <https://doi.org/10.1111/j.1365-2729.2012.00487.x>
- Voogt, J. M., & Roblin, N. P. (2012). A comparative analysis of international frameworks for 21 st century competences: Implications for national curriculum policies. *Journal of Curriculum Studies*, 44(3), 299–321. <https://doi.org/10.1080/00220272.2012.668938>
- Voss, T., Kunter, M., & Baumert, J. (2011). Assessing teacher candidates' general pedagogical/psychological knowledge: Test construction and validation. *Journal of Educational Psychology*, 103(4), 952–969. <https://doi.org/10.1037/a0025125>
- Wahlster, W. (2017). Artificial intelligence as the driver for the second wave of digitalization. *IM+io*, (2), 10–13.
- 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>
- Yueh, H.-P., & Chiang, F.-K. (2020). Editorial: AI and robotics in reshaping the dynamics of learning. In *British journal of educational technology*. Advance online publication. <https://doi.org/10.1111/bjet.13017>
- Yurtseven Avci, Z., O'Dwyer, L. M., & Lawson, J. (2020). Designing effective professional development for technology integration in schools. *Journal of Computer Assisted Learning*, 36(2), 160–177. <https://doi.org/10.1111/jcal.12394>