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From TPACK to DPACK: The "Digitality-Related Pedagogical and Content Knowledge"-Model in STEM-Education

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Abstract: Digitalization is a keyword in the discourse of educational science, but it is often linked to technological challenges, although digital changes occur throughout society. Therefore, STEM teachers are required to cope with technological changes in the subject, the increasing and diverse education and training technologies, and the ever-changing paths of information and communication of adolescents in their role as members of a changing society and culture. The TPACK-model focuses educators' professional knowledge based on teachers' expertise concerning technological knowledge per se and the pedagogy and content of their subjects. In contrast, knowledge relevant to daily life and social and cultural interaction beyond this is not clearly included in the TPACK-model at present. This article proposes supplementing the TPACK-model with the knowledge components of digital cultural transformations (digitality) and, therefore, extending the TPACK-model to a DPACK-model, where D stands for digitality. Therefore, digital transformation in STEM teaching requires additional professional knowledge considering the transformation of communication, mediatization and society. Through this expansion, the focus should also be directed on the necessity that children and young people in the digitally shaped world must also be able to critically reflect on the processes of change and shape them in an ethically responsible manner. For this reason, teachers require professional knowledge to reflect, analyze, use and shape the digital transformation, which is regularly demanded of them by national and international educational standards. As a foundation of STEM teachers' education and training, an integrated model combining these facets of knowledge and skills is provided for discussion, and, as a result, quickly found its way into the educational policy guidelines and educational science discourses in Germany. In order to integrate the sociocultural consequences of digitalization into TPACK, this paper proposes a new hemisphere, sociocultural knowledge, which extends the existing TPACK components.

Keywords: DPACK; TPACK; professionalization; digital competencies; teacher education; STEM

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1. Introduction

The increasing speed of technical digitalization (e.g., artificial intelligence (AI)) is changing the world more and more profoundly in more and more areas. Starting with digital innovations in the economy, digitalization has gradually spread to other sectors. At the beginning of the twenty-first century, this process increasingly affected people and their daily lives [1,2] and is still ongoing, showing an interconnection between the so-called digital revolution and sociocultural change [3]. The occurring changes, initiated by the products that were manufactured and made available by industry, primarily affect the

individual user, as well as their social practices [4]. However, the resulting potentials and the users' changed behavior then trigger further changes via the dynamic processes that go beyond technological facilitations in everyday life and affect the interpersonal sector. Smartphones, for example, not only offer new technological possibilities for communication, but also change the way we communicate. Through ubiquitous access to information, the increased use of digital media (e.g., multimedia, digital video, AR, VR), new possibilities of human–computer interactions (e.g., ChatGPT) and new cultural practices (e.g., remix, commenting and sampling), they are also changing the way we perceive and classify the world. Virtual contacts and communication change our individual social network, our way of thinking, and maybe the way we make decisions or solve problems. In addition, these changed social practices, reciprocally, could be drivers for new digital tools and media [5,6]. Such social facets were, and still are, not sufficiently considered in theories or models describing the effects of, and strategies to deal with, digitalization. As a result, the considerations based on such concepts, with the classification of digitization mainly being considered a technological process, often fall short of capturing the associated changes and challenges. From this perspective, various authors specifically highlight aspects that are also socioculturally relevant [1,4,7,8] to clarify the links, interactions, and conclusions affecting the sociocultural sphere, leading to concepts such as deep mediatization and digitality.

The limitations of the technological perspective can also be found in the educational sector and related models, which address the need for effective technology integration for pedagogy, describing various components of knowledge necessary for the digitalization of teaching in situated contexts, e.g., TPACK [9]. While the TPACK model introduces a third primary form of knowledge, referred to as Technology Knowledge, which extends the PCK model of Shulman [10] to describe the teachers' professional knowledge of integrating technology in their teaching, sociocultural knowledge is not an explicit element or primary form of knowledge in the complex, multifaceted nature of teacher knowledge described by the model. Koehler and Mishra [11] state that teachers must create a form of knowledge that "goes beyond the three separate knowledge bases" (Technological, Pedagogical and Content Knowledge) of the model by understanding their interrelation.

One question that we will address in this paper is whether the knowledge that needs to go beyond the three primary forms of knowledge might involve a fourth primary dimension of knowledge, sociocultural knowledge. Teaching concerns people and society, and therefore clearly has a social component; furthermore, disciplines related to all three primary forms of knowledge (technological, content-related, pedagogical) have sub-disciplines with a sociocultural focus, as is clearly recognizable in the use of socio-informatics for technology, social-pedagogy for pedagogy and the integration of socio-scientific issues into, e.g., modern STEM teaching as an example for the content domain. The link between sociocultural and technological aspects is covered by the already established construct of digitality. Digitality is a newly coined term that combines the words digital and materiality or reality [8]. These changes affect not only social life and forms of communication, but also artistic forms of expression and scientific progress, and self perception and development, including the use of artificial organs [12–15]. All these cultural and media transformation processes go beyond purely technological changes, and thus not only change everyday life, but also the content and methods of science and the central reference points of education.

Using the Digitality Related Pedagogical and Content Knowledge (D-PACK) model [16,17], a theoretical framework has been developed so that these diverse processes of change are also systematically taken into account in the professionalization of teachers, as well as in research on teacher competences.

The DPACK model is well-established in the German-speaking countries Austria (e.g., [18]), Germany (e.g., [19–27]) and Switzerland (e.g., [28]), and has inspired several colleagues and the Standing Conference for the Ministers of Education and Cultural Affairs in Germany. With more than 50 citations since 2019, the DPACK-model has achieved high recognition and "*it becomes evident that the broader understanding of the DPACK model*

is conceptually groundbreaking" ([29] p. 17). The core idea of the DPACK model is that digitization is not only limited to technological aspects, but also touches on social, societal, or even ethical aspects, which are then also linked in the respective intersections with CK and PK [29]. The DPACK model is mainly used as a theoretical framework to ground empirical studies on teacher professionalization.

With the introduction of a sociocultural hemisphere, we want to focus teachers' pedagogical knowledge more on the sociocultural conditions and consequences of learning in a world shaped by technological and media developments. If we consider the analogy of the expanding universe raised at the beginning of the article, the integration of sociocultural aspects is crucial because, metaphorically speaking, in this analogy, the classroom is something like the Big Bang.

2. TPACK and Its Limitations

Mishra and Koehler [9] contended that the TPACK framework, introduced in 2006 as a conceptual and theoretical framework exploring the connection between technology and teaching, highlighted the limitation of focusing solely on technology without considering its application. They argued that the mere introduction of technology into educational settings does not suffice, and attributed the gap between envisioned outcomes and actual educational practices to this oversight.

This view clearly underlines that there is more than just the technological aspect. Even supplementary considerations of how the technology is used may also fall short. For processes including social components, such as in the case of teaching and learning, the social perspective might be additionally relevant, since, on the one hand, social norms have an influence on technology acceptance and usage [30,31], while, on the other hand, the use of technology can cause changes in social behavior and cultural and communication practices [2,32], or even change social norms [33]. In order to reflect the TPACK framework in this regard and discuss possibly sensible adjustments, some aspects of the framework and its development should be considered in more detail.

A central perspective when developing the TPACK framework was "that a conceptually based theoretical framework about the relationship between technology and teaching can transform the conceptualization and the practice of teacher education, teacher training, and teachers' professional development" ([9], p. 1019f). According to Mishra and Koehler [9], the absence of explicit discussions regarding technology and its connection to pedagogy and content does not imply the insignificance of these matters. Instead, it indicates that a lack of emphasis is placed on technology-related issues and their significance in educational contexts. They regard knowledge of technology as an essential aspect of overall teacher knowledge and integrated it as an explicit domain in such a way that technology cannot be viewed "as constituting a separate set of knowledge and skills that has to be learned" ([9], p. 1024), but instead is an integral element of teacher education. In subsequent publications (e.g., [34]), this is described as an extension of Shulman's characterization of teacher professional knowledge [10] to explicitly consider the role that knowledge about technology can play in effective teaching by defining three major knowledge components that form the foundation of the TPACK framework. Additionally, they assert that gaining knowledge regarding technology empowers individuals to perform diverse tasks utilizing information technology and explore alternative approaches to accomplishing a given objective [35]. These three knowledge components and their corresponding fields of interaction can be summarized as follows (cited from [34], p. 102):

- *"Content knowledge (CK) refers to any subject-matter knowledge that a teacher is responsible for teaching.*
- *Pedagogical knowledge (PK) refers to teacher knowledge about a variety of instructional practices, strategies, and methods to promote students' learning.*
- *Technology knowledge (TK) refers to teacher knowledge about* ***traditional*** *and new technologies that can be integrated into curriculum.*

Four components in the TPACK framework, address how these three bodies of knowledge interact, constrain, and afford each other as follows:

1. *Technological Content Knowledge (TCK) refers to knowledge of the reciprocal relationship between technology and content. Disciplinary knowledge is often defined and constrained by technologies and their representational and functional capabilities.*
2. *Pedagogical Content Knowledge (PCK) is to Shulman's (1986) notion of "an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (p. 8).*
3. *Technological Pedagogical Knowledge (TPK) refers to an understanding of technology can constrain and afford specific pedagogical practices.*
4. *Technological Pedagogical Content Knowledge (TPACK) refers to knowledge about the complex relations among technology, pedagogy, and content that enable teachers to develop appropriate and context-specific teaching strategies."*

This is the fundamentum of the TPACK model, which was introduced as the TPCK model (without "A"). Although this description of the model seems quite clear, some points are still missing compared to the TPACK model that is used at present (a summary of the evolution or development of the TPACK model is given by Zhang and Tang, 2021). In 2007, Thomson and Mishra modified the initial model and changed from TPCK to TPACK, stressing the interaction of the three domains and the necessity of the "Total PACK-age" ([36], p. 368). In 2008, the three knowledge domains were set in relation to contexts [37], and an additional circle was drawn to represent these contexts (http://www.tpack.org/, accessed on 20 July 2023). In the course of the theoretical considerations, Koehler and Mishra emphasized that "*there are social and institutional contexts that are unsupportive of teachers' efforts to integrate technology*" ([37], p. 6), and described some of these more social barriers ([37], p. 8–10), with a primary focus on teachers. However, they state that "*the diversity of teachers, students, and technology coordinators who operate in this social context bring different goals, objectives, and beliefs to the table, and thereby contribute to the wickedness of this problem*" and that, "*indeed it is the social, psychological complexity of these problems—rarely their technological complexity—that overwhelms standard problem-solving approaches*" (p. 11). Rosenberg and Koehler [38] showed that, when contexts are considered in connection with the TPACK model, those related to students and society are less likely to be included than those related to school factors and teachers, e.g., curricular standards or cultural aspects. An indication of the putative relevance of knowledge related to these contexts, which also covers social issues, is given by the modification of the model by Mishra [39] and other empirical findings.

The results of published studies show inconsistent empirical support of the seven-factor structure of TPACK, since these components are often highly correlated, resulting in different factor structures [40–42]. These findings raise serious concerns regarding the framework's construct and the question of to what extent the components of TPACK are, in fact, seven separate components [34]. Mishra [39] considered the potential for alternative factor structures beyond the seven in the core model, and proposed adjustments accordingly.

Mishra [39] renamed and reframed the outer dotted circle representing the contexts as "Contextual Knowledge (XK)", introducing an additional knowledge domain as the eighth component that is of critical importance. He argues that we should work toward an increase in this contextual knowledge. Similar to the initial development of the TPACK model, Mishra states that "it is not that researchers and practitioners have not paid attention to context only that this nuance was not integral to the current representation of TPACK, hence limiting its application" ([39], p. 77). According to these considerations, one possible interpretation is that context, and especially sociocultural perspectives (e.g., sociocultural knowledge, social practices, and norms), might not have been sufficiently considered in the model, and additional focus on this field might be helpful. To question this interpretation, we should ask ourselves what contexts we encounter in classrooms regarding students, society, and educational goals at present.

The daily action of teachers within these contexts ultimately also leads to the further development of their available knowledge. Concerning the construction of knowledge, Olofson, Swallow and Neumann [43] state that an individual's interaction with external structures and the subsequent interpretations between those interactions are relevant components of knowledge construction. They argue, with a focus on person-to-person interactions, that social constructivism describes intersubjective experiences that contribute to knowledge construction and use TPACK to discuss teachers' knowledge construction practice as "*a process of equilibrating intrapersonal, technological, and interpersonal influences*" ([43], p. 198), which is sometimes dominated by input from students, the school culture or other contexts. In Rosenberg and Koehler's [38] systematic review, the contextual perspective is considered within research on TPACK. They based their work on the heuristic framework of Porras-Hernandez and Salinas-Amescua [44], which explicates different levels of context ("*micro, meso and macro*") and relevant actors (teachers, students). Both should be considered to strengthen teachers' TPACK "*in a rich setting of social interactions, resources, scaffolds, and supports*" ([38], p. 5). These contextual perspectives need further clarification, especially related to the sociocultural fund of knowledge carried by the teachers, which should be reflected by teachers' and students' social and cultural technology-related norms and practices. Sociocultural perspectives, especially those considering the digital transformation of social processes and culture, may not only be an important facet of TPACK, but also affect the construction of related knowledge supporting the development of TPACK. Since strategies and models for developing TPACK should consider the necessary knowledge and which knowledge base is available upon which to build [34], a structured clear perspective on relevant components and contexts is crucial for teacher education and their intersection. In this paper, we start from a theoretical point of view, based on a literature review on the sociocultural consequences of digital change and, in Germany, a very influential paper by an expert interdisciplinarian group to present what we believe to be a more holistic, but also structured approach to a systemic consideration of these sociocultural consequences of digital change.

3. Sociocultural Consequences of the Digital Change

3.1. General Perspective on Sociocultural Components in Daily Live and Education

The contextual perspectives described above need further clarification, primarily related to the sociocultural fund of knowledge carried by the teachers, which should be reflected by teachers' and students' social and cultural technology-related norms and practices. The relevance of sociocultural aspects should encourage us to look closer at this domain and its significance in our society and daily life, especially when preparing teachers for teaching in a world where sociocultural practices and media are increasingly digitally shaped within a digitally transformed classroom.

Sociocultural theory is a perspective in education that emphasizes the importance of social and cultural context in the learning process. This theory was basically developed by Lev Vygotsky, a Russian psychologist, and it suggests that social interactions and cultural practices play a crucial role in shaping cognitive development. According to sociocultural theory, learning is a social process that occurs through interactions with others in a specific cultural context. Vygotsky [45] argued that individuals acquire knowledge and skills through a process of socialization, where they engage in activities with others who are more skilled or knowledgeable in a particular domain. In educational settings, sociocultural theory emphasizes the importance of collaborative learning environments, where students work together to solve problems and share knowledge [46]. This approach recognizes that students come from diverse cultural backgrounds and have different levels of knowledge and experiences and seeks to create a learning environment that is responsive to these differences.

Teachers who adopt a sociocultural perspective are encouraged to create learning opportunities that allow students to engage in meaningful social interactions with their peers and with more knowledgeable others. This can involve strategies such as group

work, peer tutoring, and collaborative problem-solving activities, taking into account, for example, the possible cultural effects of working with each other.

Overall, sociocultural theory highlights the importance of recognizing and valuing students' diverse cultural and social backgrounds and providing learning opportunities that are responsive to their needs and experiences.

In doing so, educators have the opportunity to facilitate students in cultivating a more profound comprehension of their surrounding world, as well as equipping them with the necessary knowledge and skills essential for their success as learners and active members of society.

3.2. Sociocultural Theory and Digital Transformation

Sociocultural theory can also be applied to digital transformation, as it recognizes the importance of the social and cultural context in shaping the adoption and use of digital technologies and media. Sociocultural theory suggests that the success of digital transformation initiatives depends not only on the technology itself, but also on the social and cultural factors that shape its adoption and use. Sociocultural theory emphasizes the importance of considering the social and cultural context in digital transformation initiatives, and of creating a culture that values and supports the use of digital technologies. By doing so, organizations can ensure that their digital transformation initiatives are more effective, and that they deliver the desired benefits to both employees and customers—in our case, teachers and students.

Sociocultural theory was applied in the early 2000s [47] to guide teachers' use and integration of instructional technology. There has been limited empirical research on the cultural factors that affect user acceptance of technology, and the ways in which culture impacts this acceptance remain uncertain [48]. Therefore, future studies could investigate the "how" aspects of this issue by exploring the primary cultural dimensions and their associations with user acceptance of technology.

In digital transformation, competencies for the digital world are no longer limited to technological skills. For the European Commission ([49], p. 10) "*Digital competence involves the confident, critical, and responsible use of, and engagement with, digital technologies for learning, at work, and for participation in society. It includes information and data literacy, communication and collaboration, media literacy, digital content creation (including programming), safety (including digital well-being and competencies related to cybersecurity), intellectual property related questions, problem-solving and critical thinking*".

The digital change has led to new conditions and forms of the knowledge society, with an increase in the importance of competencies regarding the digital world and a changed understanding of digital competence/digital literacy. Although digital competence and digital literacy are closely linked and blurred in some countries, digital competence is often understood as the skills people should have in the current society. In contrast, digital literacy is used as a collective term for computer, information, and media literacy [50]. In view of the increased importance of digital technologies in a sociocultural context and, therefore, in teaching situations, as outlined above, we see the requirement of including a sociocultural dimension within TPACK. By taking the sociocultural dimension into account, we can interconnect the digital literacy and digital competence. With the term sociocultural in combination with present technology, we understand the need for a connection of skills to allow for participation in social life with media, computer and information literacy.

Teaching and learning within a digital transformation should be understood as an amalgam of digital, symbolic and material realities. Hepp [4] notes, in his work on deep mediatization, an ongoing recursive transformation where general social practices are entangled with media and physical practices become media practices as well.

"Rules [. . .] are inscribed into data processing algorithms which are reapplied to the social phenomena they collect data on and through these recursive loops they are themselves an influential factor in the transformation of social phenomena" ([4], p. 13). From this perspective, the process of digital transformation should be seen as an ambivalent process

of construction, deconstruction, and reconstruction of these sociocultural practices within the entangled digital infrastructure, data and algorithms that consistently shape everyday life and influences with increasing proportion in addition to teaching and education.

3.3. The Reciprocal Connection between Technological and Socio-Cultural Developments

On the one hand, these sociocultural contexts shape the way that digital technologies are adopted and used within society. This includes factors such as social norms, cultural values, and historical legacies, which influence the way that people interact with technology. These sociocultural factors can either facilitate or hinder the adoption of digital technologies and can shape the way that they are used in a particular context. On the other hand, the science content of digital transformation refers to the technological advancements and innovations that are driving this transformation. This includes the development of new hardware, software, and data technologies that enable new forms of digital interaction and communication. The science content of digital transformation is constantly evolving, with new breakthroughs and innovations emerging on a regular basis. The high dynamics of digital transformation arise from the rapid pace of technological change and the need for society to adapt to these changes. At the same time, the situatedness of digital technologies means that they are deeply embedded within specific social and cultural contexts and cannot be understood in isolation from these contexts. This creates a high level of complexity and reciprocity, as changes in the sociocultural context can impact the development and use of digital technologies, while advances in science and technology can have far-reaching effects on society and culture. For example, the incorporation of emoticons, emojis, and stickers has a significant influence on communication dynamics. These visual elements have the potential to complement affective expressions, shape interpersonal connections, and aid in the mutual comprehension of messages [51]. The interconnectedness of sociocultural practices and technological innovation can easily be illustrated by the example of social media: they influence innovations and developments—technological as well as social—to a great extent [52].

An all-encompassing comprehension of digital transformation triggers a shift in emphasis from the predominantly positivist–cognitivist perspective of the TPACK construct towards a constructivist outlook that recognizes the significance of situationally and subject orientation to a greater extent.

In the traditional positivist–cognitivist view, the TPACK construct is primarily understood as a set of objective and measurable knowledge domains that teachers must acquire in order to effectively integrate technology into their pedagogy. However, with the advent of digital transformation, it is becoming increasingly clear that this perspective fails to account for the complex and dynamic nature of technology integration in educational contexts, even though, as presented above, recent work has identified and highlighted the importance of context within the TPACK model.

A more constructivist view of the TPACK construct considers the situatedness of knowledge and the role of individual subjectivity in shaping technology integration practices. This includes a recognition of the importance of context, culture, and the unique needs and perspectives of individual learners in shaping the integration of technology in teaching and learning.

Therefore, to fully understand the impact of digital transformation on education, it is necessary to adopt a more constructivist perspective of the TPACK construct. This shift in focus requires greater attention to the subjective experiences of teachers and learners, as well as a more nuanced understanding of the situatedness of technology integration practices.

It seems that the advancement of digital transformation is an inevitability for humanity.

Chan [12] describes the “Digitalized Self” as a newly emerging form of self that exists between the physical and digital realms, characterized by shifts in essential concepts and experiences, self-concepts, and self-identities. This transformation occurs due to the interplay of the self, mind, and brain with the world, culture, and society on various levels

and systems in society. In the digital age, this process involves psycho-sociocultural and neurobiological processes that shape the human mind (and even the brain and its function) and its various mental faculties (c.f. [53]).

The concept of the "Digitalized Self" presents two contrasting possibilities: collective strength and advancement, or individual fragility and volatility. These polarized endpoints pose a significant challenge for humans to reconcile, particularly for young individuals who have grown up as (almost falsely named) "Digital Natives" [54]. Most importantly, it is essential to maintain a boundary between the "Digitalized Self" and the fundamental "Self" that is inherent in human beings. These funds of identity "*can be conceived as subjective productions that include a wide range of psychological processes and as a dynamic system of sense (thinking, imagination, agency, affectivity, perception) to understand ourselves and generate alternatives and possible futures. And [. . .] they can involve spaces for the critical analysis of oneself and reality, while also working in opposition to normalized, majority-focused discourses and practices*" ([55], p. 176).

Thus, education, and especially teacher education and training, must acknowledge and reflect the sociocultural perspective when fostering TPACK. In order to link this systematically with the T-PACK model, the following section presents an interdisciplinary model that is significant in Germany and is used as the basis for the further development of T-PACK into D-PACK.

3.4. Discourse from a German Perspective → The Frankfurt-Triangle Model

To systematically take into account the connection between technological and sociocultural developments from an educational perspective, a framework model for educational processes in the digital world has been developed in Germany, incorporating multiple disciplinary perspectives of researchers in media sociology, media theory, informatics, and school practitioners: the so-called Frankfurt Triangle model [56]. The model's center focuses on observing digital artifacts, e.g., social networks, fake news, rabbit holes, and artificial intelligence applications. The model works through these artifacts using three perspectives and associated processes.

The Frankfurt Triangle (see Figure 1) highlights the importance of three perspectives in education for and about digital transformation: the technological–media perspective, the sociocultural perspective, and the interaction perspective.

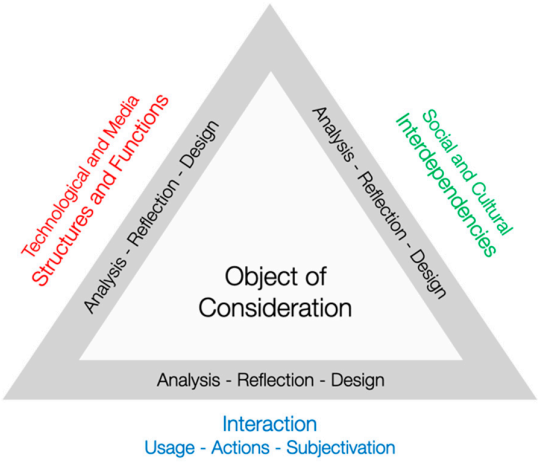

Figure 1. The Frankfurt Triangle as a form of multidisciplinary interplay between technology, culture, and society in educational concepts.

The technological–media perspective involves understanding the technologies and media that are driving digital transformation. This perspective focuses on the technological aspects of digitalization and aims to develop learners' knowledge and skills in using and working with digital tools and technologies. The processes of analysis, reflection, and

design are essential in this perspective to enable learners to understand the impact of technology on their lives and society.

The sociocultural perspective focuses on the broader societal and cultural changes due to digital transformation. This perspective aims to develop learners' critical thinking skills and enable them to understand the complex interplay between technology, society, and culture. Analysis, reflection, and design processes are essential in this perspective to allow for learners to identify and understand digital transformation's social and cultural implications.

The interaction perspective focuses on human–computer interaction and the design of user interfaces. This perspective emphasizes individuals and their usage of digital media and systems, including the reasons behind their use, the intended objectives, the sociocultural context within which they operate, and their level of involvement in digital transformation. The processes of analysis, reflection, and design are essential to this perspective to enable learners to understand the needs and preferences of users and to design digital products and services that meet their needs.

The Frankfurt Triangle model emphasizes the importance of considering the interplay between technology, culture, and society in educational concepts related to digital media and systems. The model asserts that, to enable participation in the digital world, learners must understand not only the technological and medial structures and functions of digital media and systems, but also the sociocultural interactions and modes of use, action, and subjectivation that shape their use.

The ultimate goal of educational concepts related to digital media and systems, according to the Frankfurt Triangle model, should be to enable learners to analyze, reflect on, and design digital artifacts and the phenomena associated with them in the context of these three perspectives. By developing these skills, learners can better understand and judge the impact of digital media and systems on individuals, society, and culture. This can help them to use digital media and systems in more informed and ethical ways, and to contribute to the development of digital media and systems that are beneficial to society. Considering these perspectives, contexts, and educational goals, adequate knowledge for teachers must be outlined in corresponding models.

The Frankfurt Triangle provides an orientation framework for shaping the sociocultural perspective in an extension of the TPACK model, leading to the DPACK model presented in this article. At the heart of the DPACK model lies the notion of digital fluency, which involves the ability to effectively use digital technologies and tools to achieve pedagogical goals. Unlike the TPACK model, which focuses on the integration of technology within specific content areas, the DPACK model encompasses a broader range of skills and knowledge, including the use of digital technologies to enhance communication and collaboration, facilitate critical thinking and problem-solving, and foster creativity and innovation. The DPACK framework explicitly places more emphasis on the sociocultural context of technology integration. This includes a consideration of the ways in which digital technologies can be used to address equity and social justice issues, as well as the potential impact of technology on learners' well-being and development. Through the incorporation of these considerations into the framework, the DPACK model provides a more holistic approach to technology integration that is better aligned with the evolving needs of contemporary educational settings. It is not sufficient for teachers to have knowledge about digital technologies; they also need knowledge about media developments and social consequences and individual forms of use and their prerequisites.

Teaching is embedded in the sociocultural contexts, frameworks and dynamics influenced by media and technology. By introducing the DPACK model, which adds another domain or sphere with a focus on sociocultural knowledge, we can direct our attention to the networking of existing TPACK knowledge with other relevant knowledge domains in the digitally transformed education and society.

4. Result: The DPACK Model as a Consequence of the Theoretical Consideration

Sociocultural knowledge (SK) is a relevant element of teacher education [57,58]. In an educational context, Rakhimova et al. [59] (p. 56) describe it as "*the abilities of intercultural communication with the representatives of different cultures*", including "*the knowledge of social and cultural life, understanding of native and foreign culture, knowledge of native and foreign language*". To effectively engage with individuals from diverse cultural backgrounds, the acquisition of sociocultural knowledge is imperative in developing sociocultural competencies. This knowledge enables individuals to navigate interactions and relationships with partners who are deeply rooted in different cultural contexts.

Expanding the TPACK model with SK as the fourth knowledge dimension results in the formation of new, additional intersections or components. The integration of sociocultural knowledge can be visualized using an additional sphere that interacts with the three established knowledge domains in the TPACK model. This approach helps to illustrate the interconnections and interdependencies between the various knowledge domains and highlights the importance of considering the sociocultural context as a comprehensive domain with a wide range of factors. This is why we integrate SK as a three-dimensional sphere surrounding TPACK, resulting in the DPACK model (see Section 4.8).

4.1. Sociocultural Knowledge (SK)

Sociocultural knowledge (SK) is the knowledge of sociocultural aspects described in Section 3.

Using the established dimensions of TK, CK and PK as a basis, SK can be placed into the center of this fundamentum (Figure 2). By choosing a top-down perspective, a two-dimensional projection, with SK as the central overlay above the known representation of the core of the TPACK model, is obtained (Figure 3).

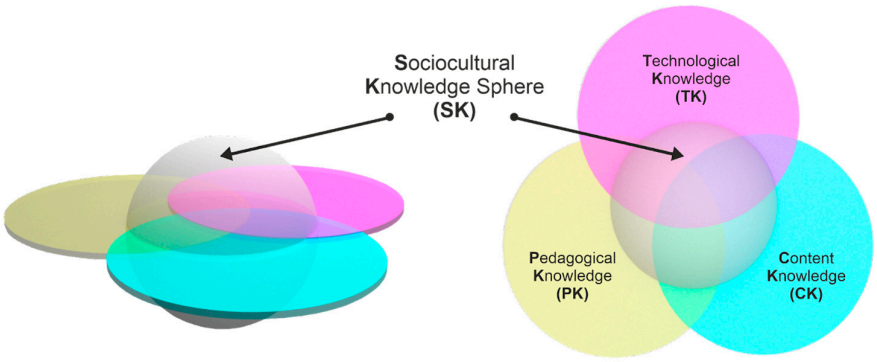

Figure 2. Extension of the TPACK model with a sociocultural knowledge domain. The side view shows the interaction with the TPACK model while the projection from above shows the resulting intersections with established TPACK domains.

To understand the resulting construct, there is no need to define the components that are already integrated into the (original) TPACK model, since there is no reason to replace or change them. Therefore, the descriptions of these components given in Section 2 are still valid and of significance. Using this fundamentum allows for the integration of the sociocultural knowledge domain (SK) and the resulting intersections to be the focus. STK, SPK, and SCK serve as intersections of just two domains, while STPK, SPCK, and STCK (see Figures 4 and 5) are represented by overlaps of three, and STPACK of four, knowledge domains.

4.2. Digitality Related Knowledge (DK) (= Sociocultural Technological Knowledge (STK))

Sociocultural Technological Knowledge (STK) (see Figure 6) is the knowledge needed to understand interactions between sociocultural background and the use of technology. These interactions are seen as reciprocal, and thus technology influences social dynamics

and interactions as well. Following the Frankfurt Triangle Model, three perspectives are relevant to this type of sociocultural knowledge:

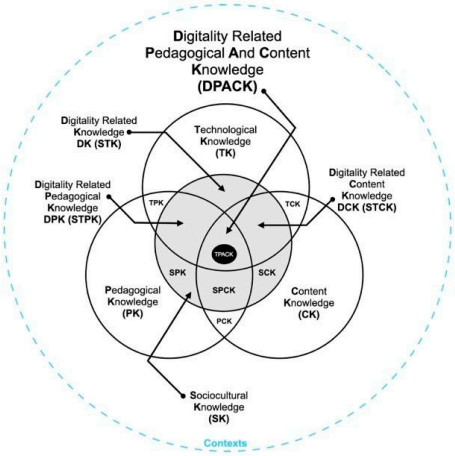

Figure 3. Sociocultural knowledge (SK).

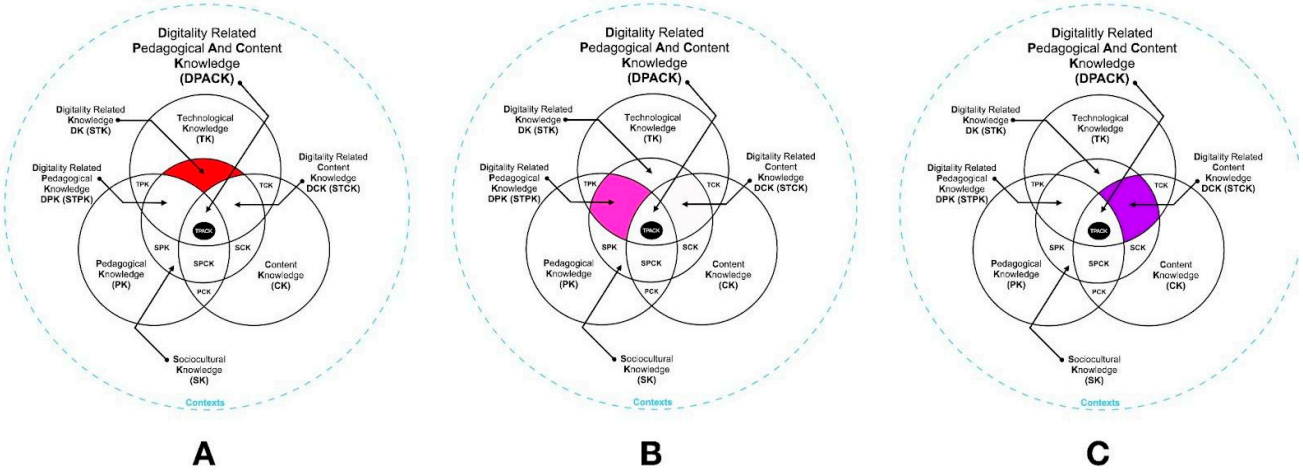

Figure 4. Sociocultural overlaps with TK, TCK and TPK (Digitality related knowledge intersections). From the overlapping fields, new technology-related knowledge fields with socio-cultural aspects emerge, such as STK ((**A**), aka DK), STPK ((**B**), aka DPK) and STCK ((**C**), aka DCK).

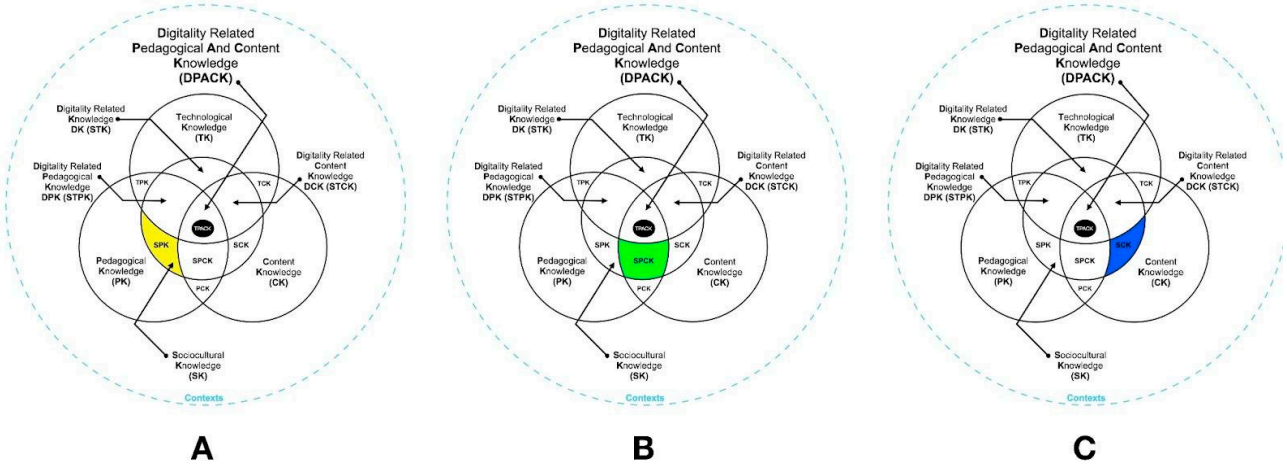

Figure 5. Sociocultural overlaps of CK and PK without TK. From the overlapping areas, new fields of knowledge emerge that are not related to technology but cover socio-cultural aspects, such as SPK (**A**), SPCK (**B**), and SCK (**C**).

- Technological media perspective;
- Sociocultural perspective;
- Interaction perspective.

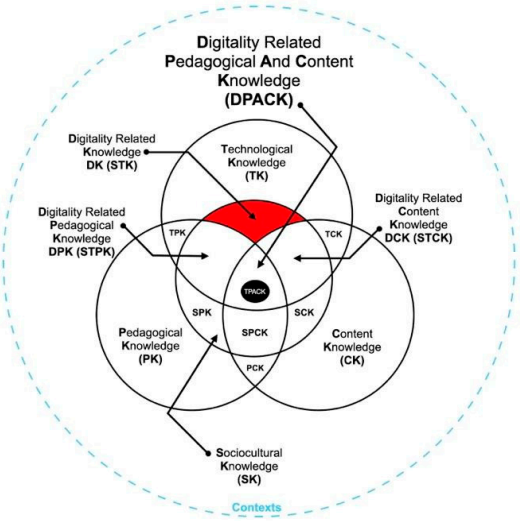

Figure 6. Digitally related knowledge (DK) (= sociocultural technological knowledge (STK)).

For teacher education, the interaction between these perspectives in the sense of STK is meaningful. The development of technology is only one essential factor of digital transformation. The interaction between the three perspectives is relevant as well, e.g., in digital transformation cultural practices, digital technologies and media are reciprocally transformed in a coupled manner. Living with digital technologies also means living in a world where new cultural practices and media communication possibilities emerge. Knowledge and critical reflection of these media- and technology-enriched forms of communication and practices are substantial components of digital transformation knowledge, in addition to purely technology-related knowledge. The aim is to develop a critical awareness of the highly interconnected nature of sociocultural, technological and media-receptive/productive practices. Therefore, for teacher education, a reflective practitioner needs to consider information literacy, media literacy, data literacy and knowledge of the relationship with sociocultural practices and habits.

Such knowledge is gained, for example, by the emerging research on social-informatics that focuses explicitly on studies covering social aspects of computerization [60]. A short definition is given by Kling ([61], p. 217): "*Social informatics is the body of research that examines the design, uses, and consequences of information and communication technologies in ways that take into account their interaction with institutional and cultural contexts*". This covers the thoughts and aspects of Stalder's "Digitalität" [8] and technology acceptance, which is influenced by sociocultural aspects [62,63]. Especially this knowledge domain is a prerequisite for STEM teachers when teaching based on a science–technology–society model [64].

4.3. Digitality Related Pedagogical Knowledge (DPK) (= Sociocultural Technological Pedagogical Knowledge (STPK))

We refer to the description of technological pedagogical knowledge given by Koehler and Mishra ([34], p. 102), which states that "*TPK refers to an understanding of technology can constrain and afford specific pedagogical practices*". STPK is knowledge that specifically addresses the sociocultural foundations of learning with technology (see Figure 7).

In the integration phases of non-native speakers, for example, this could be the use of distance teaching involving appropriate mother-tongue teachers, digital materials or platforms from the respective country of origin that are adapted to previously familiar school traditions or the use of translation systems. Furthermore, the availability of suit-

able technologies and devices, depending on social class or cultural group, must also be considered.

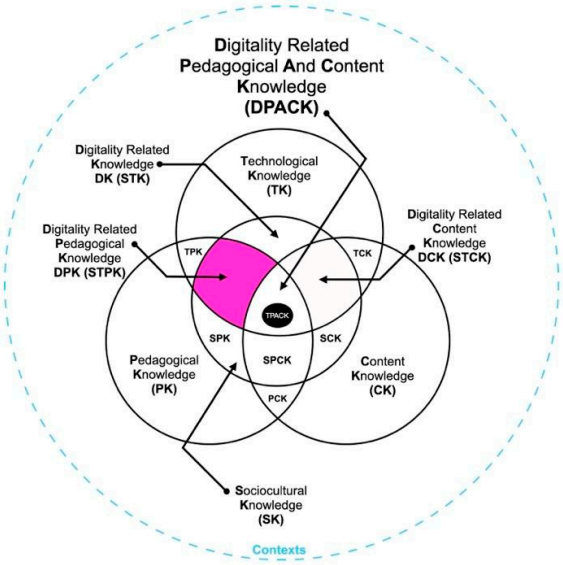

Figure 7. Digitality related pedagogical knowledge (DPK).

4.4. Digitality Related Content Knowledge (DCK) (Sociocultural Technological Content Knowledge (STCK))

Referring to the description of Technological Content Knowledge given by Koehler and Mishra ([34], p. 102) that TCK "*refers to knowledge of the reciprocal relationship between technology and content. Disciplinary knowledge is often defined and constrained by technologies and their representational and functional capabilities*" and that, e.g., in science education, this is linked to the use of technology in the scientific field, STCK covers knowledge that is necessary when rethinking technology-related ethical choices as a cultural consensus [65], the lack thereof, and how this will guide scientists, governments, and corporate agencies (in general, actors in the respective field of content) in handling, for example, Big Data. The respective knowledge relates to fields covered by the subject of the lectures given by teachers regarding content. This knowledge also refers to content-specific STK (see Figure 8).

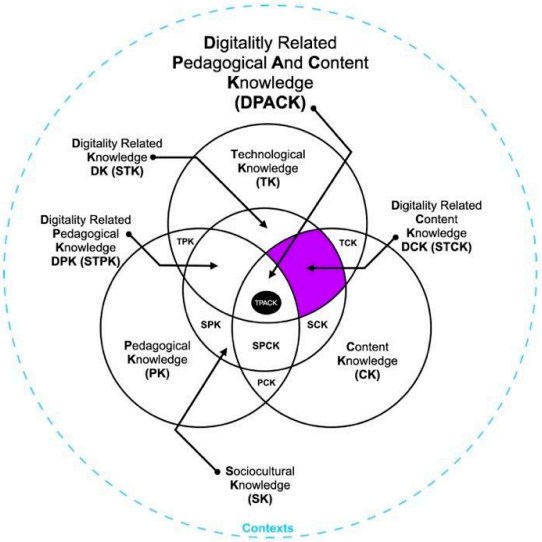

Figure 8. Digitality related content knowledge (DCK).

4.5. Sociocultural Pedagogical Knowledge—SPK

Sociocultural content knowledge (SPK) (see Figure 5A) is the knowledge of sociocultural aspects in pedagogical contexts. Educational systems differ from country to country. Cultural differences have always been associated with different educational perspectives and structures. However, with the increasing globalization and diversity within societies, consideration of these differences is increasingly becoming a challenge in education. Therefore, sociocultural factors such as origin, religion, sexual orientation, or ethnicity (cf. Big 8 of Diversity Management) must be considered when designing learning processes. Wetzel et al. [57] list frameworks addressing this area, showing that this field is not new (e.g., Ladson-Billings [66], dealing with *culturally relevant pedagogy*, or Marosi et al. [67], defining *culturally responsive pedagogy* in science education), although the focus of the model has not been on this area to date. An easy-to-understand example is the possible impact of fasting during Ramadan on student performance, which must be considered when planning lessons.

4.6. Sociocultural Content Knowledge (SCK)

Sociocultural content knowledge (SCK) (see Figure 5C) is the knowledge of sociocultural aspects in the corresponding science subject. In science education, this is often referred to as socio-scientific issues (SSI), which are often seen as a special type of context-based learning in the design of science curricula. The thematization or problematization of SSIs in science education is important to ensure that the science curricula are relevant and to promote interest in learning science [68]: "*There has been many attempts to address students' lack of interest in learning science through context based science education, such as the Science-Technology-Society movement, which highlight societal issues to enhance students' critical thinking skills and social responsibility*" ([69], p. 2).

4.7. Sociocultural Pedagogical Content Knowledge (SPCK)

Referring to the description of Pedagogical Content Knowledge given by Koehler and Mishra ([34], p. 102), that *PCK "is to Shulman's (1986) notion of "an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction" (p. 8)"*, SPCK refers to sociocultural knowledge of topics in which sociocultural aspects are of particular importance (see Figure 5B). Culturally responsive sexuality education [70] and education on nutrition or evolution can be cited as examples. These areas of instruction may need to be adapted to the sociocultural background of the target group using adequate strategies.

4.8. Digitality Related Pedagogical and Content Knowledge (DPACK) (Sociocultural Technological Pedagogical Content Knowledge (STPCK)

Referring to the description of *Technological Pedagogical Content Knowledge* given by Koehler and Mishra ([34], p. 102) that *TPACK "refers to knowledge about the complex relations among technology, pedagogy, and content that enable teachers to develop appropriate and context-specific teaching strategies"*, STPACK (aka. DPACK) specifically includes the sociocultural knowledge necessary for optimal lesson planning (see Figure 9).

The DPACK model, therefore, places greater emphasis on the sociocultural context of technology integration. Through the incorporation of these considerations into the framework, the DPACK model provides a more holistic perspective on technology integration (see Figure 10). In conclusion, the DPACK framework builds on the foundational TPACK model to provide a more comprehensive approach to technology integration that is better-suited to the complex and rapidly evolving demands of contemporary education. By placing greater emphasis on digital fluency and sociocultural considerations, the DPACK model represents an evolution in the field of technology integration that has the potential to enhance the effectiveness and impact of pedagogical practice.

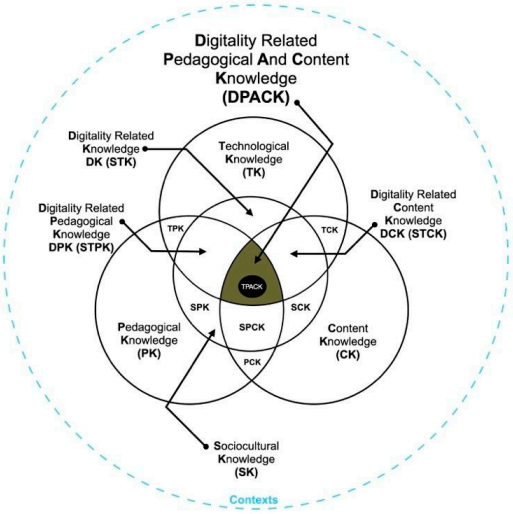

Figure 9. Digitality related pedagogical and content knowledge (DPACK).

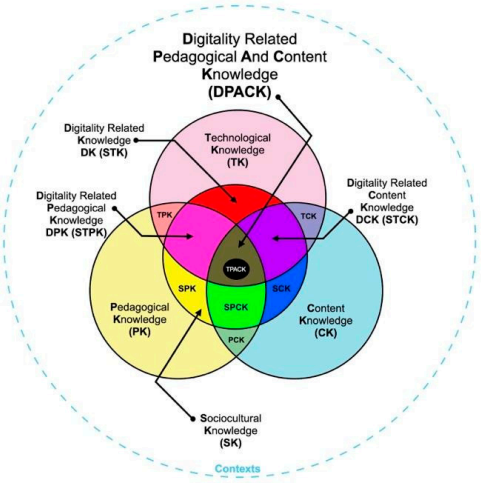

Figure 10. The complete DPACK model.

5. Discussion and Conclusions

While the technological aspect was still dominant at the beginning of digitalization, it has become evident, since the universal availability of data networks and mobile technologies, that not only are technological changes significant for information, communication, and educational processes, they are also significant for sociocultural and media developments in digitality, presenting new challenges and opportunities for learning and teaching. The importance of social and cultural factors in digital transformation led us to extend the previous domains of technological, pedagogical, and content knowledge and their intersection with the new domain of sociocultural knowledge and further intersections to consider the importance of sociocultural changes in digitality and to clarify the importance of sociocultural knowledge in STEM education.

Sociocultural knowledge plays a role in designing teaching–learning processes and has been studied from different perspectives for decades. In light of the increasing heterogeneity in the everyday classroom and the constantly changing cultural dynamics and practices observed in society and schools, sociocultural insights are becoming increasingly crucial for teacher education and professionalization.

It is essential to clearly and transparently prioritize this aspect of professional knowledge to ensure it receives the necessary attention as it competes with other equally important teacher education areas. In the digital transformation, sociocultural aspects become even more relevant, leading to new perspectives on educational concepts. Deep mediatization and digitality have been identified as relevant to education. Thus, to enhance

the TPACK model, it is necessary to expand it in multiple dimensions. Theoretical and intellectual analyses comparing the concept of the DPACK model to the original TPACK model and its extensions provide evidence for the incorporation of SK into the model.

From this expansion to include aspects of digitality, which we summarize with the letter D (for digitality-related knowledge), two strands of teacher professionalization emerge:

The first strand is about the question regarding what significance the sociocultural changes triggered by digital and media change have for educational content and objectives. If, for example, developments in the field of artificial intelligence make new tools available for dealing with content-related questions or research tasks, not only do new opportunities for promoting competencies arise, but also new requirements for the subject areas that are dealt with in the classroom and the associated competencies. The extension of the TPACK model to the DPACK model based on the model used in Germany, the highly acclaimed interdisciplinarian Frankfurt Triangle Model (Figure 1), thus also relates to questions about the selection and further development of educational content and objectives in a world shaped by digitality, which is constantly evolving. Competencies for life and learning in this digitally shaped world must also be developed. From an educational perspective; however, this cannot exclusively focus on competencies for adapting to the existing digitally shaped world. Since young people must also be put in a position not only to help shape the ongoing digital transformation, but also to shape their lives in the digitally shaped world, they must also be put in a position to analyze and reflect on sociocultural developments in the digital world, to use them for their own individual benefit, and to shape them regarding social developments. To provide professional support for this development of competencies, teachers also need competencies for analyzing, reflecting on, using and shaping the sociocultural consequences of technological developments [56,71]. Education is closely related to ethical issues. Being an ethical teacher involves fulfilling duties regarding fairness, reverence, compassion, attentiveness, and dedication to students' well-being, among other commendable qualities, while conducting the teaching process. Acknowledging the impact of this ethical conduct and the dissemination of these values and virtues is also essential [72].

These ethical issues retain their importance regarding technological developments [73]. Meanwhile, the TPACK model's proposal to include ethical content areas is also available [74,75]. For example, teachers must consider privacy issues when using new technologies, as well as preventing social inequalities in the use of digital technologies, and considering and ethically evaluating changes in the relationships of individuals in the classroom [75]. Nevertheless, the educational relevance of the emerging changes and the related ethical issues is not limited to what happens in the classroom; it must extend to problems outside the classroom if schools are also to make students' lifeworlds, and the new forms of communication emerging in the wake of digital transformation, the subject of instruction. The expansion of TPACK to include a digitality-related domain and the associated sociocultural conditions and technologies support the development of ethical competence dimensions through an analytical view of the social consequences of technological and media developments. The great challenge for teachers in the 21st century is thus not only to analyze and reflect on the complexity and dynamics of technological and sociocultural developments and to use and shape these processes of change, but also to specifically promote children's competencies in these areas. By adding the new sociocultural area to the TPACK model, the focus of teacher professionalization is also directed to this area to enable teachers to use technological change in a critical and reflective way for the formulation of new educational goals and content.

The second strand deals with the question of the significance of sociocultural aspects in general, particularly the sociocultural consequences of digital transformation for teaching–learning processes in the classroom.

Koehler and Mishra ([37], p. 14) originally described PK as *"a generic form of knowledge that applies to student learning, classroom management, lesson plan development and implemen-*

tation, and student evaluation. It includes knowledge about techniques or methods used in the classroom, the ***nature of the target audience*** *and strategies for evaluating student understanding. A teacher with deep pedagogical knowledge understands* ***how students construct knowledge and acquire skills****, and* ***how they develop habits of mind and positive dispositions towards learning.*** *As such, pedagogical knowledge requires an* ***understanding of cognitive, social and developmental theories of learning*** *and how they apply to students in the classroom"* (note: we highlighted important parts). This description raises the question as to what extent sociocultural knowledge is already covered by PK or even PCK. There have been other efforts to extend or modify the TPACK model by adding sociocultural-related knowledge and it is worth having a look at the results. The complex TPACK-XL model with thirty-one constituent knowledge constructs [76] introduces knowledge of educational psychology and knowledge of educational sociology. Since sociology explicitly addresses "*human social behavior, patterns of social relationships, social interaction, and aspects of culture associated with everyday life*" (according to the definition of sociology given by Wikipedia), the sociology-related ideas of this model modification are also covered by the integration of SK. When Saad and colleagues state ([76], p. 57) that *"in some respects, it might be true that TPACK-XL sacrifices parsimony"*, it might be reasonable to raise the question of whether a less complex model would be easier to handle and how granular a suitable model has to be. By the assumption, that—based on the description of Koehler and Mishra [37]—PK already includes relevant aspects of educational psychology, our less granular DPACK model considers the essential ideas of the TPACK-XL without generating too many areas of knowledge that must be considered at the same time. DPACK may offer benefits in terms of manageability compared to TPACK-XL, as it simplifies the complexity while retaining the essential knowledge domains. Depending on the description of, e.g., PCK, which may still be under discussion [77], further perspectives such as students' comprehension of the subject matter, educational settings, sociocultural factors, and educational psychology aspects are implicitly considered. Thus, making sociocultural perspectives explicit might help in teacher education and corresponding research.

The comparison of the DPACK model and possible deductive conclusions with empirical data on the TPACK model could also support the usefulness of such a model approach. Looking at studies that examine the influence of the TPACK knowledge domains on the genesis of TPACK, strong correlations between individual domains emerge in many cases and studies [78]. Koehler and colleagues [34] argue that *"theoretically TPK and TPACK should relate (and therefore correlate) to one another"* | *[. . .] since [. . .] "TPACK, in part, derives from an understanding of TPK"* p. 106). As an alternative explanation, the existence of a fourth knowledge component—such as SK, which intersects with the types of knowledge in the TPACK model—could affect the measurement of these knowledge types. Assuming that the non-explicit consideration or integration of SK in a model could result in the construction of items and instruments that implicitly include SK aspects, the resulting lack of selectivity could cause such correlations. Also, the hypothetical existence and function of SK as a general factor in a bifactor model accounting for varying proportions of the indicator variance would probably not result in detectable problems (e.g., crossloadings) in, for example, a confirmatory factor analysis [79]. This implies that the presence of such a domain should not be contradicted by any existing data on CFAs. Kopcha et al. [80] (p. 94) refer to other studies and express "*a growing concern that the boundaries between TCK, TPK, and the other technology-related constructs are difficult to establish in a practical sense*". Based on numerous studies, they also state that "the lack of consistency and clarity across [. . .] studies supports the need to further examine the nature of the constructs in the framework itself", since the confirmation of a seven-factor structure does not succeed beyond doubt. Depending on the context of studies and the relevance of, e.g., a sociocultural domain in the corresponding settings, the resulting detectable factor structure may vary (e.g., [81]).

Moreover, it is difficult to obtain precise results on whether the data from the TPACK analyses are more consistent with integrative or transformative models. When distinguishing between transformative and integrative models, the presence of relevant sociocultural

knowledge could explain the observed correspondence between the two models. The presence of SK and the resulting overlap, depending on the instrument being used and the specific case, potentially means that the survey of, for example, PK and TPK conducted in the studies includes relevant aspects of SPTK and SPK. Accordingly, depending on the content, context, and instrument, PK would include SPK in parts. A possible transformative effect of SPK would then be represented in integrative models as an apparently integrative effect of PK.

As possible explanations for the observed discrepancies, Schmid et al. ([78], p. 10) name the exact formulation of items and "*that the interplay of TPACK knowledge components is likely to differ across contexts (e.g., subject, school level, educational culture)*", which particularly refers to the sociocultural aspects of the latter hypothesis.

Depending on the perspective, the upstream DPACK model has different benefits. With regard to relevant facets for teacher education, it emphasizes the relevance of sociocultural aspects, which are apparently not (either anymore or yet) at the foreground in the context of the current debate about technology. With regard to empirical research, it offers a theoretical approach to investigate and clarify the inconsistencies that have arisen to date. It remains to be seen whether the structure of the DPACK model can be empirically confirmed and explain the observed discrepancies. Like the initial TPACK model, the DPACK model also creates a theoretical framework that now needs to be empirically tested and validated (outside of the DACH area). In particular, the systematic variations in and analyses of the areas of intersection (e.g., STCK and sociocultural interactions in the use of social media) appear to be facilitated by the DPACK model for future research.

However, even if the model's structure cannot be confirmed through empirical means at present, it is crucial to continue the discussion it has sparked about the significance of sociocultural knowledge in teacher education, especially with regard to the first strand of our discussion, in which we emphasize the importance of sociocultural changes in digital transformation for the formulation of educational goals and the selection of educational content, and the need to address ethical issues in the promotion of teacher competencies in the digital transformation.

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