



# Digital Competencies for Science Teaching: Adapting the DiKoLAN Framework to Teacher Education in Switzerland

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Prospective teachers need both general and subject-specific digital competencies. However, available competency frameworks usually address only non-subject-specific general digital competencies. Although the joint framework curriculum of the German-speaking cantons of Switzerland not only provides a comprehensive definition of expected digital student competencies, but also suggestions for linking them to and implementing them in subject lessons, there is still no integral planning and structuring for subject-specific teacher training in the canton of Thurgau. For a curricular design of the promotion of subject-specific digital competencies, three competency frameworks for the study programs Primary level, Secondary level 1, and Secondary level 2 at the Thurgau University of Education were derived in expert interviews based on the DiKoLAN framework (Digital Competencies for Teaching in Science Education). While there are significant overlaps, the original reference framework clearly needs to be adapted. Furthermore, there are important commonalities between the newly formed individual competency frameworks. The methodological approach has proven to be fruitful and is recommended to follow-up studies and studies with similar research questions for imitation.

**Keywords:** digital competencies, science education, competency framework, interview study, Q methodology, curriculum development, Switzerland

## INTRODUCTION

Competent use of digital media, knowledge of digital media, and the ability to use this knowledge in a problem- and goal-oriented manner are indispensable in all areas of life. This relates both to responsible participation in society and to the requirements of the digital job market, since society is constantly evolving due to the influence of digital information and communication technologies (Partnership for 21st Century Skills, 2006; Deutschschweizer Erziehungsdirektoren-Konferenz [D-EDK], 2014a; Standing Conference of the Ministers of Education and Cultural Affairs [KMK], 2016; Battelle for Kids, 2019; Federal Office of Communications [OFCOM], 2020). The Fourth Industrial Revolution is leading to the implementation of highly networked systems, such as the

Internet of Things, a broad and everyday use of sensors and technical assistance systems, high-level automation, and the use of cyber-physical systems, as well as artificial intelligence, Big Data, and machine learning (e.g., Schwab, 2016). Hence, future workers – today’s students – need different (new and digital) competencies than their predecessor generations.

The digital transformation also ensures that new technologies such as virtual and augmented reality, artificial intelligence, cloud computing, and 3D printing emerge as new instructional approaches and possibilities in the education sector and change the way we learn. Thus, digitalization opens up new ideas and approaches to design teaching and learning processes (Mayer, 2014; Girwidz et al., 2019).

While it was assumed around the turn of the millennium that students would grow up as *digital natives* – since digital media are now ubiquitous in everyday life and everyone uses the Internet from early childhood (Prensky, 2001a,b) – many studies now show that this myth is untenable. This applies to the availability of digital technologies (Fraillon et al., 2020), the use of technology in everyday life (Thompson, 2013; Fraillon et al., 2020), the hoped-for effectiveness of use of digital media in teaching-learning processes (Thompson, 2013), and the digital competencies of learners (Fraillon et al., 2013, 2014, 2020; Thompson, 2013; Kirschner and De Bruyckere, 2017).

Even if students have the technical equipment at their disposal and can operate it per se, this does not mean that they also have the corresponding *computer and information literacy* (CIL; Fraillon et al., 2013, 2014, p. 17, 24). Fraillon et al. (2014, p. 24) explicitly doubt that appropriate competencies can be acquired without coherent learning programs. Thus, CIL must be part of school-based education. However, learning in school is largely subject-bound, which is why the promotion of CIL must also be organized in a subject-bound manner (Deutscheschweizer Erziehungsdirektoren-Konferenz [D-EDK], 2014a; Huwer et al., 2020). The same applies to in-service teacher education (Mayer and Girwidz, 2019). Hence, the development of corresponding competencies should not take place in specially created subjects, but in the existing subjects (Deutscheschweizer Erziehungsdirektoren-Konferenz [D-EDK], 2014a; Standing Conference of the Ministers of Education and Cultural Affairs [KMK], 2016, p. 15f). Accordingly, all teachers themselves must have corresponding competencies and at the same time become media experts in their subject-related responsibilities (Standing Conference of the Ministers of Education and Cultural Affairs [KMK], 2016, p. 24). In concrete terms, this means that teachers must be able to use digital media in their respective subject lessons in a professional and didactically meaningful way, as well as reflect on their content (Standing Conference of the Ministers of Education and Cultural Affairs [KMK], 2016, p. 25).

However, the targeted promotion of learners’ general digital competencies in subject-specific instruction must not neglect the teaching of subject-specific content required by the curriculum. Hence, (a) a distinction must be made between general competencies and subject-specific competencies, and (b) the promotion of general digital competencies must be combined with the teaching of subject-specific digital

competencies as typical subject methods (Deutscheschweizer Erziehungsdirektoren-Konferenz [D-EDK], 2014a; Thyssen et al., 2020). Therefore, teachers need subject-specific digital competencies in addition to general pedagogical digital competencies.

A major part of pre-service and in-service teacher training is subject-specific. This applies in particular to courses that focus on the concrete planning, design and implementation of lessons, since the lessons to be designed are intended to convey the subject content of the respective subject. Therefore, subject-specific digital competencies related to teaching should also and above all be anchored in the subject didactics. Therefore, the development of corresponding competencies must be made mandatory in subject-specific teacher training for all teaching professions (e.g., Standing Conference of the Ministers of Education and Cultural Affairs [KMK], 2016, p. 25; State Secretariat for Education, Research and Innovation [SERI], 2017, 2021; Federal Office of Communications [OFCOM], 2020).

It is a core task of all teachers to support the digital transformation of teaching, learning and society. However, it is still largely unclear which digital competencies are required by which learners and at which point the development of competencies should be supported, and by whom. Digital education is only partially and often insufficiently integrated into school and university curricula and, above all, is hardly linked to subject-specific and subject-didactic aspects, which are needed for concrete and effective subject-specific instruction.

The common framework curriculum for the *Volksschule* (this comprises grades 1–9 and thus primary and secondary level 1) in all German-speaking cantons of Switzerland – *Lehrplan 21* (Deutscheschweizer Erziehungsdirektoren-Konferenz [D-EDK], 2014a,b) – is an exception in this respect. With this curriculum, a curricular interlocking of the supra-subject module *Media and Informatics* (Deutscheschweizer Erziehungsdirektoren-Konferenz [D-EDK], 2014b, p. 2) with the subjects taught was created. The digital competencies of students are explicitly considered from four perspectives: the lifeworld perspective, the career perspective, the educational perspective, and the teaching-learning perspective (Deutscheschweizer Erziehungsdirektoren-Konferenz [D-EDK], 2014a, p. 483f). Depending on the subject, content from the area of *Media* or content from *Informatics* is dealt with to a greater extent. The natural science subject group “*Natur, Mensch, Gesellschaft* [Nature, Human, Society]” (which is equivalent to science and social science) establishes references to both the area of media and computer science. Accordingly, teachers in this group of subjects need particularly broad digital teaching skills. Although comprehensive competency expectations are set for pupils in the module *Media and Informatics*, this interlocking focuses partly (but not exclusively) on more technical and application-related aspects of media use and leaves room for supplementation with, among other things, connections to the importance of media use in the subject area taught (Thyssen et al., 2020), new teaching-learning materials added during the COVID-19 pandemic and, in particular, issues of digitality (Huwer et al., 2019a,b). Required competencies on the part of teachers are implicitly addressed insofar as selected teaching-learning media are explicitly listed in *Lehrplan 21*.

Therefore, curricular structuring and integration into teacher training courses require not only a definition of the competencies to be acquired in the course of study but also a framework of digital competencies for teachers, sub-structured according to the various actors in teacher training.

While several proposals for general digital competencies have already been published by governmental (e.g., Deutschschweizer Erziehungsdirektoren-Konferenz [D-EDK], 2014a; Kelentrić et al., 2017; National Institute of Educational Technologies and Teacher Training, 2017) and supranational organizations (UNESCO-IICBA, 2012; Redecker, 2017; UNESCO, 2018) as well as by non-governmental interest groups (e.g., ISTE, 2017; Battelle for Kids, 2019) and individuals (e.g., Falloon, 2020), there is so far only one internationally received orientation framework specifically for teaching in the natural science subjects: DiKoLAN – Digital Competencies for Science Teaching (Figure 1; Becker et al., 2020; Kotzebue et al., 2021; Thoms et al., 2021). DiKoLAN describes digital core competencies that should be mandatory for all prospective teachers of science subjects at the end of the university education phase. DiKoLAN is thus specific to the tripartite teacher education system in Germany, which clearly separates three phases: a 4–5-year university education, a one to 2-year teacher traineeship (depending on the federal state), and the subsequent professional career, with partly voluntary and partly mandatory teacher training in the sense of lifelong learning. While the second phase is largely conducted at schools and student teachers have extensive teaching duties, contact with students in the first phase of training at the university is usually rather limited or subordinate. For better readability and to clearly distinguish the existing framework from the framework developed in this study, the original DiKoLAN is abbreviated below as DiKoLAN-GER.

Teacher training universities are faced with the institutional task of making the development of digital competences mandatory in subject-specific teacher training for all teaching professions and are also obliged to do so by the state (e.g., Standing Conference of the Ministers of Education and Cultural Affairs [KMK], 2016, p. 25; State Secretariat for Education, Research and Innovation [SERI], 2017, 2021; Federal Office of Communications [OFCOM], 2020).

Teacher training at the Thurgau University of Education, on the other hand, is characterized by an early combination of theoretical studies at the University of Education and practical training at cooperating schools. Therefore, DiKoLAN-GER cannot simply be adopted for the curricular implementation of the promotion of digital competencies at the Thurgau University of Education for structural reasons alone. Likewise, the subject contents of the educational curricula at the Thurgau University of Education differ in part significantly from those of German states and universities. In addition, a curriculum of digital competencies should also allow for and promote site-specific sharpening, expansion, and prioritization. Finally, linguistic adjustments in the formulation of competency expectations may be necessary if a framework developed for Germany is to be applied in Switzerland.

The aim of the research described here is (a) to develop a site-specific framework of digital competencies for teaching in science subjects for teacher education at Thurgau University of Education and (b) to evaluate the method used in this process with regard to its suitability for the systematic development of site-specific and subject-specific frameworks of digital competencies.

## MATERIALS AND METHODS

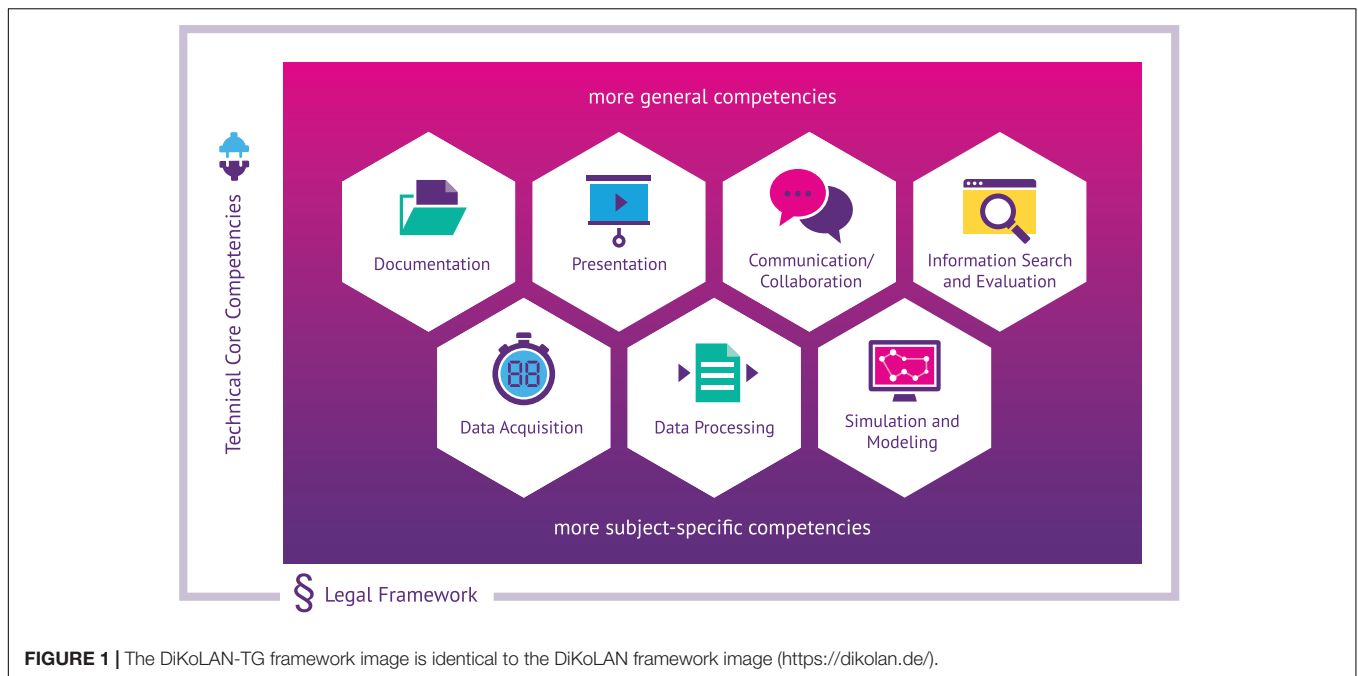
In order to determine the digital core competencies required for the teaching profession in the natural sciences in the Canton of Thurgau, which must be acquired by all prospective teachers,  $n = 9$  lecturers involved in science didactic teacher training at the Thurgau University of Education were interviewed in the spring semester of 2021. The interviews (120 min each) proceed in three phases. First, interviewees were asked to sort the seven core competency areas already defined in DiKoLAN-GER (*Documentation, Presentation, Communication/Collaboration, Information Search and Evaluation, Data Acquisition, Data Processing, and Simulation and Modeling*) according to their importance for the respective degree program (Primary, Secondary 1, or Secondary 2) using Q-sorts (McKeown and Thomas, 2013).

On the basis of this sorting, interviewees were asked whether any of the competence areas should be adopted or deleted in DiKoLAN-TG or, if necessary, should be supplemented. In a second phase, the interviewees were asked to discuss the internal structure of the competence areas and their orientation toward the TPACK model (Mishra and Koehler, 2006; Koehler et al., 2013) and the DPaCK model (Huwer et al., 2019a,b) as well as the competence levels *Name, Describe, and Use/apply*.

In the third and most comprehensive phase, the lecturers were asked to review each competency expectation described in DiKoLAN-GER for its suitability for teacher education in Thurgau in terms of content and language. In addition, participants were asked whether any of the competency expectations should be revised, extended, or deleted altogether. Finally, interviewees were asked to evaluate the suitability of DiKoLAN-GER as a basis for the orientation framework to be developed once again in a review of the overall system, considering the modifications necessary from the perspective of the lecturers.

## Definition of Experts, Acquisition of Participants, Sample

In this study, the focus is on science-specific digital teaching competencies. Therefore, the Thurgau University of Education site lecturers to be interviewed must be experts in teacher education, in teaching and learning in the natural sciences, as well as in subject-specific teaching with digital technologies. To ensure that all subjects interviewed met these criteria, potential participants were selected by the head of the “*Natur, Mensch, Gesellschaft* [Nature, Human, Society]” department (which is equivalent to science and social science) and the head of the Secondary 2 program. Of the  $N = 12$  experts thus identified, a



**FIGURE 1** | The DiKoLAN-TG framework image is identical to the DiKoLAN framework image (<https://dikolan.de/>).

total of  $n = 9$  could be interviewed during the designated period at the end of May/beginning of June 2021.

## Interviews

The interviews were conducted online *via* a videoconferencing platform due to the ongoing difficulties because of the COVID-19 pandemic, and the recommendation to work from home. During the interviews, participants were provided with a collaborative online board including instructional material (see **Supplementary Material**) in which (a) work could be done directly and (b) written notes during the conversations could instantly be viewed both by interviewers and interviewees and any ambiguities could be discussed directly. This procedure guaranteed a high reliability of the interviews. A timeslot of 120 min was scheduled for each interview.

## Relevance of Competency Areas

In principle it was not to be expected that any of the seven central competency areas formulated in DiKoLAN-GER would be considered unimportant for the teaching profession in Thurgau. Nevertheless, in order to identify differences across types of schools the participants were asked to rank the areas of competence separately according to their importance for the teaching profession in primary education, Secondary 1, and Secondary 2, respectively (**Figure 2**).

It was expected that for primary school teaching the more subject-specific competency areas will play a rather subordinate role and that for teaching at secondary level 1 and 2 more subject-specific competencies will be required.

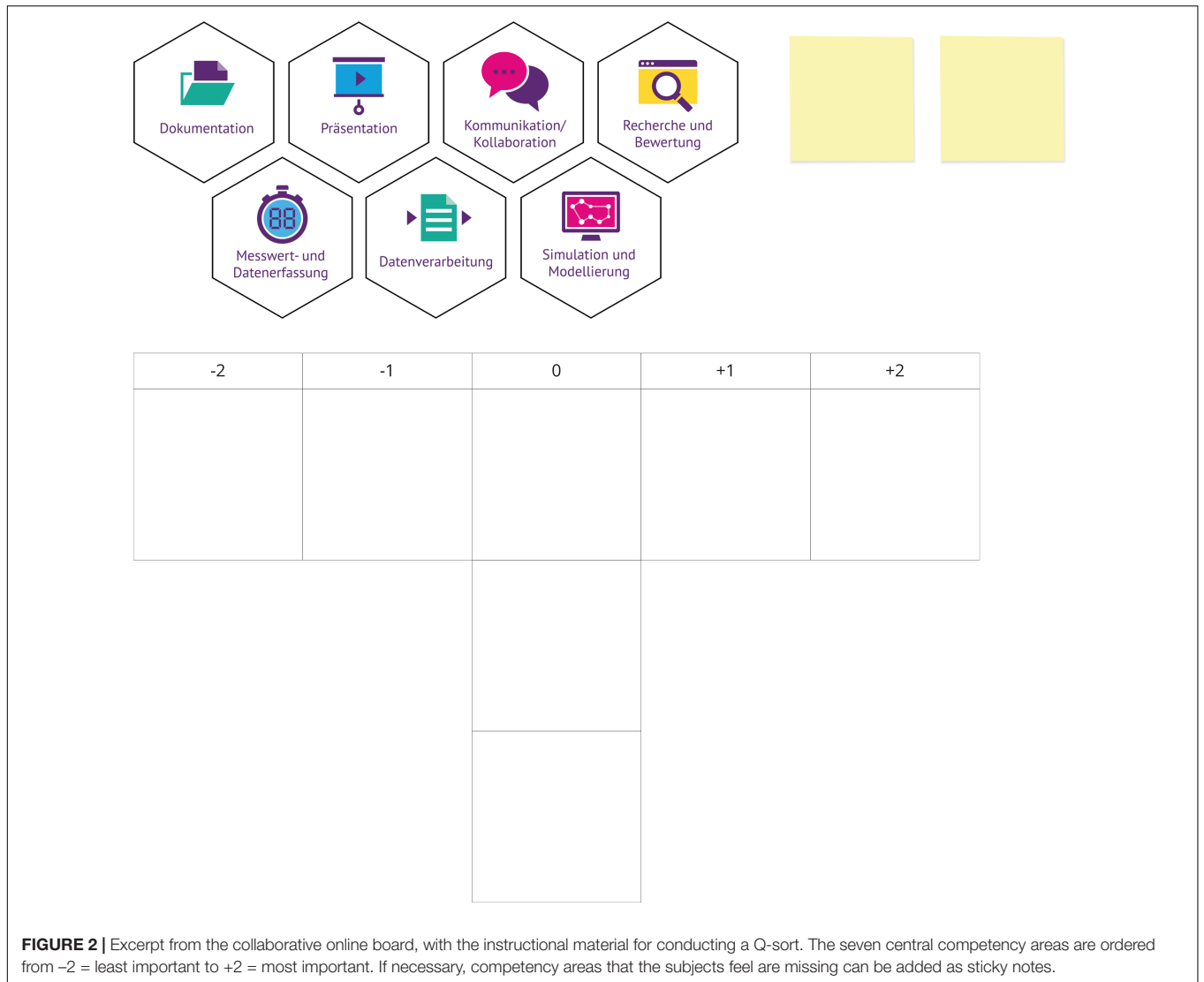
While the courses of study for the teaching profession at elementary school and at secondary level 1 start right after leaving school, the course of study for secondary level 2 is a postgraduate

course of study that requires a previous subject-matter course of study with a master's degree. The required subject knowledge is verified before admission to the program. In addition, many of the students enrolling in a secondary 2 degree program have already worked in their field and/or are already teaching in schools. Therefore, it can be assumed that these students have a generally good basic knowledge of the subject and an in-depth knowledge of typical subject-related working methods. Accordingly, the course content focuses primarily on techniques for imparting knowledge. Since science teaching in Secondary 2 includes many demonstration experiments and Secondary 2 teachers are expected to create learning and working materials themselves, it was hypothesized that there will be a special focus on presentation techniques in the course of study and the corresponding area of competence is therefore considered to be particularly important.

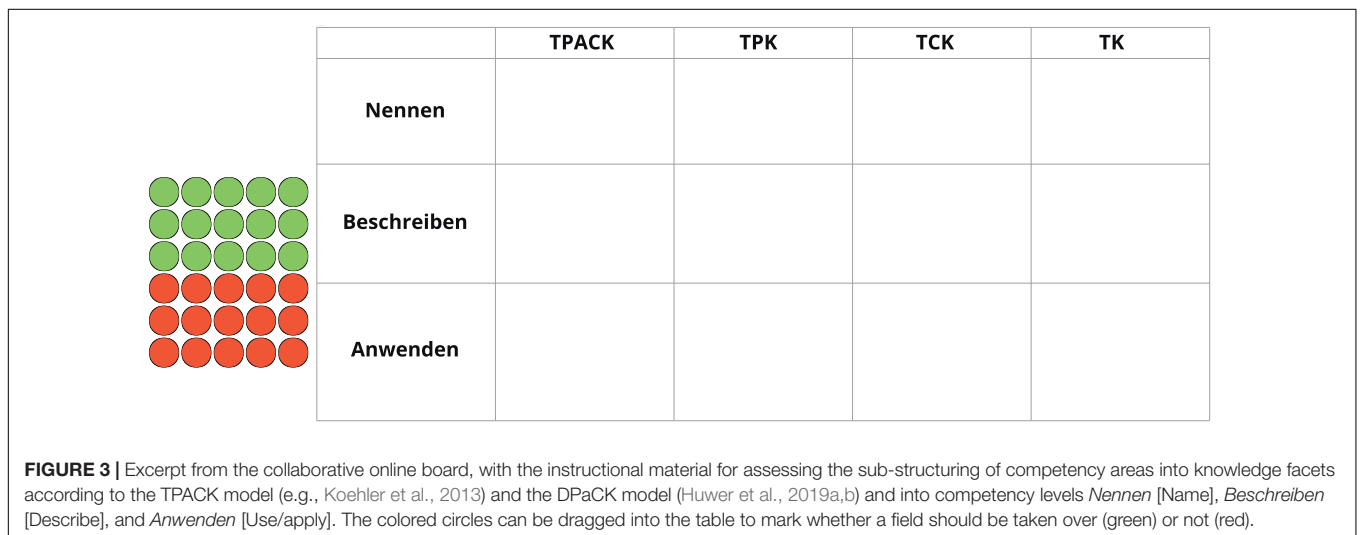
## Sub-Structuring of Competency Areas

The seven central competency areas defined in DiKoLAN-GER are sub-structured (a) in technology-related knowledge facets according to the TPACK model (Mishra and Koehler, 2006; Koehler et al., 2013) and the DPack model (Huer et al., 2019a,b), and (b) in three levels of competence: *Name*, *Describe*, and *Apply/execute*. Kotzebue et al. (2021) provide a rationale for this substructuring, discuss it in detail and present initial empirical results to support it. Participants were asked to indicate whether a distinct combination of knowledge facet and level of competence is important or unnecessary for a program of study (**Figure 3**).

It was assumed that the content-specific context is not considered important for teachers in primary education, and therefore expected that faculty in the relevant program would eliminate the TCK column altogether.



**FIGURE 2 |** Excerpt from the collaborative online board, with the instructional material for conducting a Q-sort. The seven central competency areas are ordered from -2 = least important to +2 = most important. If necessary, competency areas that the subjects feel are missing can be added as sticky notes.



**FIGURE 3 |** Excerpt from the collaborative online board, with the instructional material for assessing the sub-structuring of competency areas into knowledge facets according to the TPACK model (e.g., Koehler et al., 2013) and the DPaCK model (Huwer et al., 2019a,b) and into competency levels *Nennen* [Name], *Beschreiben* [Describe], and *Anwenden* [Use/apply]. The colored circles can be dragged into the table to mark whether a field should be taken over (green) or not (red).

	Unterrichten (TPACK)	Methodik, Digitalität (TPK)	Fachwissenschaftlicher Kontext (TCK)	Spezielle Technik (TK)
<b>Nennen</b>	<p><b>P.U.N1</b> Zu (fachwissenschaftlichen) Präsentationsmedien für den Schullehrer geeignete Alternativen nennen (z. B. statt integrierter Mikroskopkamera ein digitales Handmikroskop-kamera).</p> <p><b>P.U.N2</b> Für spezifische Lehr-Lern-Situations/ Kontexte unterschiedliche Szenarien zum sachgerechten Einsatz (adressaten-, fach- und zielgerecht) digitaler Präsentationsmedien nennen.</p>	<p><b>P.M.N1</b> Prinzipien/Kriterien zur adressatengerechten Gestaltung digitaler Präsentationsmedien (z. B. CTML nach Richard E. Mayer, Gestaltpsychologie nach Wertheimer und Palmer) nennen.</p> <p><b>P.M.N2</b> Mögliche Aspekte nennen, auf die sich der Einsatz digitaler Präsentationsmedien beim Lernen und Lehren auswirken kann, z. B. im Hinblick auf:</p> <ul style="list-style-type: none"> <li>• Zeitaufwand</li> <li>• Organisationsformen</li> <li>• Darstellungsformen</li> <li>• Methoden</li> <li>• Medienkenntnis/Einarbeitung</li> <li>• Interesse und Motivation</li> <li>• persönliche und soziale Konsequenzen</li> </ul>	<p><b>P.F.N1</b> Nennen mehrere fachspezifische/fachwissenschaftliche Szenarien und ggf. Kontexte für:</p> <ul style="list-style-type: none"> <li>• digitale Präsentationsformen</li> <li>• die digitale Präsentation von Prozessen (z. B. Zeitraffer für Osmose, Zeitlupe für Bewegungen)</li> <li>• die Verwendung von Präsentationshardware (z. B. Wärmebild-kameras, Mikroskopkameras, mobile Endgeräte mit Kameras)</li> <li>• Präsentationssoftware (z. B. Origin, Matlab), die den aktuellen fachwissenschaftlichen Anforderungen und Zitationsregeln genügt</li> </ul>	<p><b>P.T.N1</b> Nennen jeweils mehrere technische Möglichkeiten zur Präsentation:</p> <ul style="list-style-type: none"> <li>• von Inhalten unterschiedlicher Größenordnungen (z. B. Dokumentenkamera, Videokamera, Smartphone, Tablet, Mikroskopkamera)</li> <li>• von Prozessen auf unterschiedlichen Zeitskalen (z. B. Zeitlupe, Zeitraffer)</li> <li>• für ein größeres Auditorium (z. B. Beamer, interaktive Tafeln)</li> <li>• für mehrere Gruppen (z. B. Anzeige auf mehreren Endgeräten)</li> <li>• für einen einzelnen Empfänger</li> </ul>
<b>Beschreiben</b> (inkl. notwendigem Vorgehen)	<p><b>P.U.B1</b> Didaktische Voraussetzungen für den Einsatz digitaler Präsentationsmedien im Unterricht, Auswirkungen dieser auf die jeweiligen Unterrichtsverfahren sowie durch digitale Systeme ermöglichte Zugänge zu Basiskompetenzen (vor allem dem Kompetenzbereich Kommunikation) insbesondere beim inklusiven Lehren und Lernen beschreiben.</p>	<p><b>P.M.B1</b> Prinzipien/Kriterien zur adressatengerechten Gestaltung digitaler Präsentationsmedien (z. B. CTML nach Richard E. Mayer, Gestaltpsychologie nach Wertheimer und Palmer) beschreiben.</p> <p><b>P.M.B2</b> Pädagogische Voraussetzungen sowie Vor- und Nachteile beschreiben, die sich methodisch beim Einsatz digitaler Präsentationsmedien ergeben, z. B. im Hinblick auf:</p> <ul style="list-style-type: none"> <li>• Zeitaufwand</li> <li>• Organisationsformen</li> <li>• Darstellungsformen</li> <li>• Methoden</li> </ul>	<p><b>P.F.B1</b> Ausgewählte fachwissenschaftliche Präsentationsformen und -medien beispielhaft beschreiben, z. B.:</p> <ul style="list-style-type: none"> <li>• Hochgeschwindigkeitsaufnahmen von Kollisionen</li> <li>• Anfertigen von Diagrammen</li> <li>• Zeitrafferaufnahmen von Pflanzenwachstum</li> <li>• dreidimensionale Darstellungen von Molekülschwingungen</li> </ul>	<p><b>P.T.B1</b> Für jede Art der Präsentation mindestens eine Möglichkeit der technischen Umsetzung inklusive des notwendigen Vorgehens unter Bezugnahme auf aktuelle Hard- und Software sowie damit verbundenen technischen Standards beschreiben.</p> <p><b>P.T.B2</b> Die Eigenschaften/Funktionalitäten, technischen Voraussetzungen und etwaige Einschränkungen der jeweiligen Systeme beschreiben.</p>
<b>Anwenden/ Durchführen</b> (praktische und funktionale Realisierung)	<p><b>P.U.A1</b> Planung und Durchführung kompletter Unterrichtsszenarien unter Einbindung digitaler Präsentationsmedien und -formen und der Berücksichtigung geeigneter Sozial- und Organisationsformen.</p> <p><b>P.U.A2</b> Fachwissenschaftliche Darstellungen mit digitalen Medien für den Schulkontext elementarisieren.</p>	<p><b>P.M.A1</b> Auswahl bzw. Anpassung bestehender und erstellter eigener Präsentationsmedien unter Berücksichtigung der technischen Möglichkeiten und Einschränkungen sowie Prinzipien/Kriterien zur adressatengerechten Gestaltung.</p>	<p><b>P.F.A1</b> Erstellung und Vorführung von Präsentationen im fachwissenschaftlichen Kontext unter Verwendung digitaler Präsentationsmedien, z. B.:</p> <ul style="list-style-type: none"> <li>• Hochgeschwindigkeitsaufnahmen von Kollisionen</li> <li>• Anfertigen von Diagrammen</li> <li>• Zeitrafferaufnahmen von Pflanzenwachstum</li> <li>• dreidimensionale Darstellungen von Molekülschwingungen</li> </ul>	<p><b>P.T.A1</b> Inbetriebnahme, Kalibrierung und Nutzung für mindestens ein Beispiel jeder Art der oben genannten Möglichkeiten digitaler Präsentation durchführen.</p>

**FIGURE 4 |** Excerpt from the collaborative online board, with the instructional material for reviewing the competency expectations. Here in case of the competence area *Presentation* [modified from Becker et al. (2020); English translation in Kotzebue et al. (2021)].

## Competency Expectations as Objectives in a Program of Study

The central and most extensive part of the interview is the assessment of the competency expectations defined in DiKoLAN-GER by the lecturers at the Thurgau University of Education. For this purpose, the respective tables with competency expectations are successively assessed for the seven competency areas (Figure 4). In the table for each area of competency, first the competency expectations in the TK column (special tools) and then the competency expectations in the TCK column (content-specific context) are checked one by one for adoption, rejection, linguistic or content adaptation. If the competency expectation is to be adopted in DiKoLAN-TG, this is noted directly in the online whiteboard with a check mark. Deletions – even of individual parts of a competency expectation – are marked directly in the text, as are linguistic and content-related adaptations.

## RESULTS

### Importance of Competency Areas Across Study Programs

#### Q-Sorts and Factor Analysis

Q sorts were analyzed with Ken-Q-Analysis version 1.0.6 (Banasick, 2019a,b). A centroid factor analysis with three extracted centroid factors explains 79% of variance (factor 1: 57%, factor 2: 11%, factor 3: 11%; with Eigenvalues 5.1451, 0.9569, and 1.0299, respectively). After varimax rotation and flagging q sorts according to the judgment groups (Primary, Secondary 1, and Secondary 2), still 79% of variance is explained (Table 1).

Table 2 shows the ranking of importance of competency areas by type of school. The importance of the competency areas

indicated by the lecturers differs in part significantly between the groups. The factor scores correlation between Secondary 1 and Secondary 2 is relatively high ( $r = 0.6666$ ), while Primary shows low correlations with Secondary 1 ( $r = 0.1232$ ) and Secondary 2 ( $r = -0.0143$ ).

It was hypothesized that for primary school teaching the more subject-specific competency areas play a rather subordinate role and that for teaching at secondary level 1 and 2 more subject-specific competencies are required. This assumption has been confirmed insofar as the competence area *Simulation and Modeling* is seen as significantly less important in Primary than in Secondary. Furthermore, the more general competence areas *Information Search and Evaluation* and *Communication/Collaboration* are attributed a greater importance in Primary than in Secondary. It was also hypothesized that competencies in the area of *Presentation* in particular would be considered especially important for the Secondary 2 course. The results confirm this hypothesis.

### Additional Comments During the Interviews

All of the faculty interviewed considered all of the indicated competency areas to be central to teaching science and found it extremely difficult to sort the competency areas by importance to a course of study. No participant thought any of the seven central competency areas should be deleted completely. Little use was made of the opportunity to make suggestions for additional competency areas. Most faculty described the DiKoLAN-GER framework as complete. There were only two ideas for possible additions (“Digital Nature of Science” and “Feedback”), but these were still classified in the course of the discussion as being integrable into the existing areas of competencies or as not really being digital competencies. Accordingly, the basic structure of DiKoLAN-GER was adopted for DiKoLAN-TG.

**TABLE 1** | Factor matrix with defining sorts flagged: Factor 1 is flagged for Secondary 1, factor 2 is flagged for Secondary 2, and factor 3 is flagged for Primary.

Part. no.	Q sort	Factor 1		Factor 2		Factor 3	
1	p_a	-0.7101		-0.7981		<b>0.1282</b>	Flagged
2	p_b	-0.5757		-0.2351		<b>0.4761</b>	Flagged
3	p_c	0.4038		-0.0604		<b>0.7016</b>	Flagged
4	s1a	<b>0.9818</b>	Flagged	0.3186		0.0426	
5	s1b	<b>-0.1684</b>	Flagged	0.1639		0.5735	
6	s1c	<b>0.8022</b>	Flagged	0.0652		-0.0243	
7	s2a	0.0975		<b>0.7647</b>	Flagged	0.1078	
8	s2b	0.6792		<b>0.6829</b>	Flagged	0.0381	
9	s2c	0.9818		<b>0.3186</b>	Flagged	0.0426	
% explained variance		45		22		12	

Factor loadings of defining sorts on corresponding factors are marked bold.

**TABLE 2** | Factor scores with corresponding ranks.

Competency area	Primary		Secondary 1		Secondary 2		Delimitation in group comparison
	Z-score	Rank	Z-score	Rank	Z-score	Rank	
Documentation	-1.23	7	-1.51	7	-1.70	7	Consensus**
Presentation	-0.38	5	-0.85	6	0.76	2	Secondary 2**
Communication/Collaboration	1.35	2	0	4	-0.80	6	Secondary 1*, Secondary 2*
Information search and evaluation	1.36	1	-0.01	5	0	4	Primary**
Data acquisition	0	3	0.05	3	0.42	3	Consensus*
Data processing	-0.37	4	0.73	2	0	5	
Simulation and modeling	-0.73	6	1.58	1	1.31	1	Primary**

Levels of significance: \*\* $p < 0.01$ , \* $p < 0.05$ .

## Sub-Structuring of Competency Areas

All participants of the interviews were in favor of keeping the sub-structuring of the competency areas based on the TPACK/DPaCK framework as well as the three competency levels exactly the same. Especially for Secondary 1, the importance of the content-specific context was emphasized.

It was suspected that an in-depth knowledge of media use in science subject areas would not be needed for teaching in elementary schools and therefore faculty in primary education courses would be in favor of removing the TCK columns. However, none of the faculty interviewed expressed support for deletion.

For Secondary 2, students are expected to have already acquired relevant knowledge in their subject studies when they start their postgraduate studies at Thurgau University of Education. Nevertheless, the competency expectations along the content-specific context should be kept in the framework also for Secondary 2.

Since all interviewed lecturers spoke out in favor of adopting the sub-structuring of the competency expectations according to knowledge facets and competency levels without any restrictions, this subdivision of the competence expectations will also be adopted for DiKoLAN-TG.

## Competency Expectations as Objectives in a Program of Study

The findings from the interviews are very comprehensive and cannot be reproduced here in full detail. In line with the qualitative approach of this research, selected findings are therefore presented and summarized here. The three site-specific digital competency frameworks *DiKoLAN-S2*, *DiKoLAN-S1*, and *DiKoLAN-P* developed as a main objective of this study are listed in full detail in the **Supplementary Material** and compared with each other in tabular form: A full list of the original competency expectations defined in DiKoLAN-GER [previously published German original version in Becker et al. (2020), and English translation in Kotzebue et al. (2021)] and their derivatives for DiKoLAN-S2, DiKoLAN-S1, and DiKoLAN-P, based on the expert interviews. **Table 3** shows as an example the comparison of the competency expectations for the application area *Special Tools* (TK) in the competency area *Simulation and Modeling* (SIM).

In line with expectations, the smallest changes occur in the transfer of the competency expectations from DiKoLAN-GER to teacher training for teaching at secondary level II (**Table 4**). There was no competency expectation in DiKoLAN-GER that was not considered essential for science teaching in Swiss upper secondary schools by the interviewed teachers. However, 22.7%

**TABLE 3 |** Exemplary excerpt from the full results in the **Supplementary Material**.

	DiKoLAN-GER	DiKoLAN-TG-S2	DiKoLAN-TG-S1	DiKoLAN-TG-P
<b>Name</b>	<b>SIM.S.N1</b> Name several programs or web packages that can be used to perform simulations and modeling (away from a spreadsheet such as Excel)	<b>SIM.S.N1</b> Name several programs or web packages that can be used to perform simulations and modeling		
	<b>SIM.S.N2</b> Name data fundamentals, skills, and necessary prior knowledge of the operator/user required for digital modeling, such as: <ul style="list-style-type: none"> <li>◆ Programming and syntax</li> <li>◆ Hardware required (performance)</li> <li>◆ Data pool size for calculations</li> </ul>			
	<b>SIM.S.N3</b> Name several simulations and approaches to simulations: <ul style="list-style-type: none"> <li>◆ To generate data in the cognition process, e.g., with a spreadsheet program</li> <li>◆ For comparison with experimentally obtained data, e.g., with a spreadsheet program</li> <li>◆ To illustrate technical correlations, e.g., PhET simulations</li> </ul>	<b>SIM.S.N3</b> Name several simulations and approaches to simulations: <ul style="list-style-type: none"> <li>◆ To generate data in the cognition process</li> <li>◆ e.g., with a spreadsheet program</li> <li>◆ to illustrate technical correlations</li> <li>◆ e.g., PhET simulations</li> </ul>	<b>SIM.S.N3</b> Name several simulations and approaches to simulations to illustrate technical correlations, e.g., PhET simulations	
	<b>SIM.S.N4</b> Name characteristics of a simulation: <ul style="list-style-type: none"> <li>◆ The transfer of a context of meaning from one object representation to another</li> <li>◆ Structure-faithful illustration</li> <li>◆ Action-faithful illustration</li> <li>◆ Reduction of complexity</li> </ul>			
<b>Describe</b> (including necessary procedures)	<b>SIM.S.D1</b> Describe the functional scope of the named packages or programs with regard to: <ul style="list-style-type: none"> <li>◆ Parameterization</li> <li>◆ Computing time</li> <li>◆ Mathematization and GUI or model description</li> <li>◆ Output options (as graphs or data sets)</li> </ul>	<b>SIM.S.D1</b> Describe the functional scope of the named packages or programs with regard to: <ul style="list-style-type: none"> <li>◆ Parameterization</li> <li>◆ Computing time</li> <li>◆ Mathematization and GUI or model description</li> <li>◆ Output options (as graphs or data sets)</li> <li>◆ Accessibility</li> </ul>		
<b>Apply/execute</b> (practical and functional realization)	<b>D.V.S.A1</b> Perform at least one modeling exercise including simulation and results validation			

Comparison of the original orientation framework DiKoLAN-GER and the orientation frameworks derived from it DiKoLAN-TG-S2, DiKoLAN-TG-S1, and DiKoLAN-P. Competency expectations in the competency area Simulation and Modeling (SIM), knowledge and activity area Special Tools (TK). The competency expectations from DiKoLAN-GER were either adopted (highlighted in green), modified (highlighted in orange), or deleted (highlighted in red).

**TABLE 4 |** Number of competency expectations kept, changed, or deleted by framework and competency area.

Competency area	DiKoLAN-TG-S2			DiKoLAN-TG-S1			DiKoLAN-TG-P			
	DiKoLAN	Kept	Changed	Deleted	Kept	Changed	Deleted	Kept	Changed	Deleted
DOC	8	6	2	0	5	3	0	4	1	3
PRE	7	5	2	0	5	2	0	3	2	2
COM	18	16	2	0	16	2	0	16	2	0
ISE	16	11	5	0	9	5	2	9	3	4
DAQ	10	7	3	0	7	3	0	5	4	1
DAP	16	14	2	0	11	4	1	4	4	8
SIM	13	9	4	0	6	5	2	4	4	5
SUM	88	68	20	0	59	24	5	45	20	23
Percentage	100%	77.3%	22.7%	0.0%	67.0%	27.3%	5.7%	51.1%	22.7%	26.1%

of the competency expectations had to be adapted for secondary level II courses at the Thurgau University of Teacher Education.

There is a medium similarity between the competencies defined in DiKoLAN-GER and the requirements for prospective teachers in Swiss lower secondary education. 67.0% of the

competency expectations could still be adopted. However, there were also 5.7% of the competency expectations that were deleted without replacement.

DiKoLAN-GER explicitly does not focus on the training of prospective elementary school teachers. In no German-speaking



country has there been a derivation of competencies from DiKoLAN into elementary teacher education so far. About a quarter of the competency expectations from DiKoLAN-GER were deleted (26.1%) or modified (22.7%) in each case. On the other hand, 51.1% of the competency expectations from secondary education in Germany were nevertheless transferred to primary education in Switzerland.

The competency expectations formulated in DiKoLAN-GER include examples from physics, chemistry, and biology to be easily understood by prospective teachers of all sciences. However, when transferring the competency expectations from DiKoLAN-GER to DiKoLAN-TG, the examples are moved from the middle of the sentence to the end of the sentence to make the competency expectations easier to read.

## DISCUSSION

The aim of this study was firstly to derive a framework of digital competencies for teachers with science subjects that can be used in teacher training at the Thurgau University of Education from the already established framework DiKoLAN-GER (Digital Competencies for Science Teaching; Becker et al., 2020; Kotzebue et al., 2021; Meier et al., 2021; Thoms et al., 2021) and to adapt it to local conditions and particularities of the Canton of Thurgau and of Switzerland as a whole. One example is the importance of secure and permanent data storage, which is a key economic factor for Switzerland. Secondly, this study tests a procedure for the structured review of a competence framework in which its structuring and competency expectations are examined for partial adoption, adaptation, expansion and/or reformulation.

As a result of this study, frameworks of digital competencies for science teaching are now available for three of the four branches of study offered at the Thurgau University of Education (see **Supplementary Material**). These frameworks have been comprehensively revised and adapted for the location and can be directly implemented in teaching at the university. Through the direct involvement of faculty working at the university, it can be assumed that there is at least a general willingness to use the jointly developed competency framework, which will certainly facilitate future curricular adaptations.

The mixed-methods approach of this study proved to be very fruitful. The ranking of the importance of the competency areas for the respective study programs showed clear differences which could also be assigned to differences in the requirements and in the curricular design of the study programs. The intensive work with the competence expectations successively and individually led to a deeper examination and reflection of the lecturers with the contents of the competency framework, which is also manifested in the quality of the expert opinions created in this process. During the work in the collaborative online board, many complementary discussions were held between the interview partners, which provided broad and multi-layered insights into the requirements but also into already well-established

structures for the promotion of (general) digital competencies at the Thurgau University of Education. This approach can clearly be recommended for follow-up studies or studies with similar intentions.

Nevertheless, it must be kept in mind that in the interviews only lecturers from one location were questioned and the generated competency frameworks are therefore only valid for the Thurgau University of Education. It would make sense to conduct the studies at other locations in Switzerland using the same procedure in order to (a) identify the same competency expectations across locations and (b) obtain an overview of location-specific enhancements in digitization-related teacher training.

Finally, a common framework describing digital core competencies for teaching science subjects, shared by all teacher education sites in German-speaking Switzerland and considered as absolute minimum standards, is the necessary prerequisite to transfer effective courses promoting digital subject-related teaching competencies from one university to other universities (Zimmermann et al., 2021). However, not all universities of education in Switzerland need to be surveyed for this purpose, as Zimmermann et al. (2021) have already been able to show how the transfer of courses aimed at promoting digital competencies from one university to other universities can succeed if a common reference framework is shared. Accordingly, a representative sample should be sufficient to provide sufficiently meaningful and transferable results for the time being as an initiation for a nationwide discussion of digital core competencies in teacher education.

## CONCLUSION

As a result of this research, three orientation frameworks of digital competencies specific to the Canton of Thurgau are now available for teachers with science subjects, which can be used in the future for a curricular structuring of the implementation of digital competencies in teacher education at the University of Thurgau.

In addition, a procedure for transferring a competence framework from one country to another was designed and implemented, which proved to be highly suitable and can therefore stand as a prototype for similar projects. The following recommendation for subsequent studies can be derived from the experience and results of this study:

1. In the development of a framework of digital competencies for the curricular structuring of subject-specific teacher education, existing reference frameworks should be used, also in the sense of connectivity and the greatest possible transparency.
2. The orientation framework DiKoLAN-GER is well suited as a starting point for the derivation of a subject-specific orientation framework due to its science-based but nevertheless subject-unifying perspective (even for non-science subjects, see for example Alber and Starke, 2021).

3. When deriving competency expectations, as many suitable lecturers of the target location as possible should be involved (a) in order to include subject didactic as well as subject-specific, media didactic and informatics perspectives and (b) to achieve the highest possible acceptance in the subsequent curricular implementation of the competence framework.
4. The described procedure of interviewing the lecturers and making entries in a collaborative online board can be recommended without reservation.
5. The ranking based on the conducted Q-sort should also be maintained in similar projects. Despite no competency area emerged that should be deleted and the outcome competency areas resemble the template, (a) the program-specific rankings underscore the need for program-specific orientation frameworks, (b) the program-specific rankings can be used in curricular implementation, if learning goals to be achieved have to be weighted differently due to limited resources, and (c) the discussion of the competency areas and the attempt to rank them provides a low-threshold entry into the interview for the interview partners and activates the interviewees for the necessity of addressing the topic.

## DATA AVAILABILITY STATEMENT

The raw data that support the findings of this study are available on request from the corresponding author (L-JT, lars.thoms@phtg.ch).

## REFERENCES

- Alber, B., and Starke, A. (2021). Digitale Kompetenzen von Sprachtherapeut\*innen-Therapieren (DiKoST-T). *Forsch. Spr.* 9, 3–11.
- Banasick, S. (2019a). KADE: a desktop application for Q methodology. *J. Open Source Softw.* 4:1360. doi: 10.21105/joss.01360 (accessed October 22, 2021).
- Banasick, S. (2019b). *Ken-Q Analysis*. Available online at: <https://shawnbanasick.github.io/ken-q-analysis/> doi: 10.5281/zenodo.1300201
- Battelle for Kids (2019). *Framework for 21st Century Learning*. Available online at: [www.p21.org](http://www.p21.org) (accessed October 22, 2021).
- Becker, S., Bruckermann, T., Finger, A., Huwer, J., Kremser, E., Meier, M., et al. (2020). "Orientierungsrahmen digitale kompetenzen lehramtsstudierender der naturwissenschaften – DiKoLAN [Orientation framework for digital competencies of student teachers in the natural sciences – DiKoLAN]," in *Digitale Basiskompetenzen: Orientierungshilfe und Praxisbeispiele für die universitäre Lehramtsausbildung in den Naturwissenschaften [Digital Core Competencies: Orientation Guide and Practical Examples for University Teacher Training in the Natural Sciences]*, eds S. Becker, J. Messinger-Koppelt, and C. Thyssen (Hamburg: Joachim Herz Stiftung), 14–43.
- Deutscheschweizer Erziehungsdirektoren-Konferenz [D-EDK] (2014a). *Lehrplan 21 – Gesamtaufgabe*. Luzern: D-EDK.
- Deutscheschweizer Erziehungsdirektoren-Konferenz [D-EDK] (2014b). *Lehrplan 21: The Key Facts at a Glance*. Luzern: D-EDK.
- Falloon, G. (2020). From digital literacy to digital competence: the teacher digital competency (TDC) framework. *Educ. Tech. Res. Dev.* 68, 2449–2472. doi: 10.1007/s11423-020-09767-4
- Federal Office of Communications [OFCOM] (2020). *Digital Switzerland Strategy*. Available online at: <https://strategy.digitaldialog.swiss/en/actionplan/119> (accessed October 22, 2021).

## AUTHOR CONTRIBUTIONS

L-JT: conceptualization, methodology, investigation, data curation, formal analysis, writing – original draft, writing – review and editing, and visualization. CC: resources, validation, writing – review and editing, and supervision. PH: resources, writing – review and editing, and supervision. JH: resources, writing – review and editing, supervision, and project administration. All authors contributed to the article and approved the submitted version.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/feduc.2022.802170/full#supplementary-material>

- Fraillon, J., Ainley, J., Schulz, W., Friedman, T., and Duckworth, D. (2020). *Preparing for Life in a Digital World*. Cham: Springer International Publishing.
- Fraillon, J., Ainley, J., Schulz, W., Friedman, T., and Gebhardt, E. (2014). *Preparing for Life in a Digital Age*. Cham: Springer International Publishing.
- Fraillon, J., Schulz, W., and Ainley, J. (2013). *International Computer and Information Literacy Study: Assessment Framework*. Amsterdam: International Association for the Evaluation of Educational Achievement [IEA].
- Girwidz, R., Thoms, L.-J., Pol, H., López, V., Michelini, M., Stefanel, A., et al. (2019). Physics teaching and learning with multimedia applications: a review of teacher-oriented literature in 34 local language journals from 2006 to 2015. *Int. J. Sci. Educ.* 41, 1181–1206. doi: 10.1080/09500693.2019.1597313
- Huwer, J., Banerji, A., and Thyssen, C. (2020). Digitalisierung – perspektiven für den chemieunterricht [Digitalization – perspectives for chemistry teaching]. *Nachr. Chem.* 68, 10–16. doi: 10.1002/nadc.20204100187
- Huwer, J., Irion, T., Kuntze, S., Schaal, S., and Thyssen, C. (2019a). Von TPaCK zu DPaCK – digitalisierung im unterricht erfordert mehr als technisches wissen [From TPaCK to DPaCK – digitalization in education requires more than technical knowledge]. *MNU J.* 72, 358–364.
- Huwer, J., Irion, T., Kuntze, S., Schaal, S., and Thyssen, C. (2019b). "From TPaCK to DPaCK – digitalization in education requires more than technical knowledge," in *Education Research Highlights in Mathematics, Science and Technology 2019*, eds M. Shelley and S. A. Kiray (Konya: International Society for Research in Education and Science [ISRES]), 298–309.
- ISTE (2017). *ISTE Standards for Educators*. Eugene, OR: ISTE.
- Kelentrić, M., Helland, K., and Arstorp, A.-T. (2017). *Professional Digital Competence Framework for Teachers*. Oslo: The Norwegian Centre for ICT in Education.
- Kirschner, P. A., and De Bruyckere, P. (2017). The myths of the digital native and the multitasker. *Teach. Teach. Educ.* 67, 135–142. doi: 10.1016/j.tate.2017.06.001

- Standing Conference of the Ministers of Education and Cultural Affairs [KMK] (2016). *Strategie der Kultusministerkonferenz „Bildung in der digitalen Welt“ [Strategy of the Standing Conference of the Ministers of Education and Cultural Affairs "Education in the Digital World"]*. Berlin: Kultusministerkonferenz.
- Koehler, M. J., Mishra, P., and Cain, W. (2013). What is Technological Pedagogical Content Knowledge (TPACK)? *J. Educ.* 193, 13–19. doi: 10.1177/002205741319300303
- Kotzebue, L., von, Meier, M., Finger, A., Kremser, E., Huwer, J., et al. (2021). The Framework DiKoLAN (digital competencies for teaching in science education) as basis for the self-assessment tool DiKoLAN-Grid. *Educ. Sci.* 11:775. doi: 10.3390/educsci11120775
- Mayer, P., and Girwidz, R. (2019). Physics teachers' acceptance of multimedia applications—adaptation of the technology acceptance model to investigate the influence of TPACK on physics teachers' acceptance behavior of multimedia applications. *Front. Educ.* 4:73. doi: 10.3389/educ.2019.00073
- Mayer, R. E. (ed.) (2014). *The Cambridge Handbook of Multimedia Learning*. Cambridge: Cambridge University Press.
- McKeown, B., and Thomas, D. B. (2013). *Q Methodology*. Thousand Oaks, CA: SAGE Publications Inc.
- Meier, M., Thoms, L.-J., Becker, S., Finger, A., Kremser, E., Huwer, J., et al. (2021). "Digitale Transformation von Unterrichtseinheiten – DiKoLAN als Orientierungs- und Strukturierungshilfe am Beispiel Low-Cost-Photometrie mit dem Smartphone [Digital transformation of teaching units - DiKoLAN as an orientation and structuring aid using the example of low-cost photometry with the smartphone]," in *Digitalisation in Chemistry Education. Digitales Lehren und Lernen an Hochschule und Schule im Fach Chemie [Digitalization in Chemistry Education. Digital teaching and learning at university and school in the subject of chemistry]*, eds N. Graulich, J. Huwer, and A. Banerji (Münster: Waxmann Verlag GmbH), 13–27.
- Mishra, P., and Koehler, M. J. (2006). Technological pedagogical content knowledge: a framework for teacher knowledge. *Teach. Coll. Rec.* 108, 1017–1054. doi: 10.1111/j.1467-9620.2006.00684.x
- National Institute of Educational Technologies and Teacher Training (2017). *Common Digital Competence Framework for Teachers*. Available online at: [https://aprende.intef.es/sites/default/files/2018-05/2017\\_1024-Common-Digital-Competence-Framework-For-Teachers.pdf](https://aprende.intef.es/sites/default/files/2018-05/2017_1024-Common-Digital-Competence-Framework-For-Teachers.pdf) (accessed April 5, 2022).
- Partnership for 21st Century Skills (2006). *A State Leader's Action Guide to 21st Century Skills: A New Vision for Education*. Tucson, AZ.
- Prensky, M. (2001a). Digital natives, digital immigrants Part 1. *Horizon* 9, 1–6. doi: 10.1108/10748120110424816
- Prensky, M. (2001b). Digital natives, digital immigrants Part 2: Do they really think differently? *Horizon* 9, 15–24. doi: 10.1108/10748120110424843
- Redecker, C. (2017). *European Framework for the Digital Competence of Educators: DigCompEdu*. Luxembourg: Publications Office of the European Union. doi: 10.2760/159770
- Schwab, K. (2016). *The Fourth Industrial Revolution*. Geneva: World Economic Forum.
- State Secretariat for Education, Research and Innovation [SERI]. (2017). *Herausforderungen der Digitalisierung für Bildung und Forschung in der Schweiz*. Bern: SERI.
- State Secretariat for Education, Research and Innovation [SERI]. (2021). *Digitisation in Education*. Bern: SERI.
- Thompson, P. (2013). The digital natives as learners: technology use patterns and approaches to learning. *Comput. Educ.* 65, 12–33. doi: 10.1016/j.compedu.2012.12.022
- Thoms, L.-J., Meier, M., Huwer, J., Thyssen, C., Kotzebue, L., von Becker, S., et al. (2021). "DiKoLAN – a framework to identify and classify digital competencies for teaching in science education and to restructure pre-service teacher training," in *Society for Information Technology & Teacher Education International Conference*, eds E. Langran and L. Archambault (Waynesville, NC: AACE), 1652–1657.
- Thyssen, C., Thoms, L.-J., Kremser, E., Finger, A., Huwer, J., and Becker, S. (2020). "Digitale basiskompetenzen in der lehrerbildung unter besonderer berücksichtigung der naturwissenschaften [Digital core competencies in teacher education with special regard to the natural sciences]," in *Digitale Innovationen und Kompetenzen in der Lehramtsausbildung [Digital Innovations and Competencies in Teacher Training]*, eds M. Beißwenger, B. Bulizek, I. Gryl, and F. Schacht (Duisburg: Universitätsverlag Rhein-Ruhr), 77–98.
- UNESCO (2018). *UNESCO ICT Competency Framework for Teachers*. Paris: UNESCO.
- UNESCO-IICBA (2012). *ICT-Enhanced Teacher Standards for Africa (ICTeTSA)*. Addis Ababa: UNESCO-IICBA.
- Zimmermann, F., Melle, I., and Huwer, J. (2021). Developing prospective chemistry teachers' TPACK—A comparison between students of two different universities and expertise levels regarding their TPACK self-efficacy, attitude, and lesson planning competence. *J. Chem. Educ.* 98, 1863–1874. doi: 10.1021/acs.jchemed.0c01296

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