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DiKoLAN-SK – Development of a measurement instrument for academic self-concept of digitalization-related competencies in science education

Lars-Jochen Thoms [a,b,*], Till Bruckermann [c], Christoph Thyssen [d], Monique Meier [e], Lena von Kotzebue [f], Julia Arnold [g], Nadja Belova [h], Simon Z. Lahme [i], Benedikt Heuckmann [j], Stefanie Lenzer [k], Bernadette Schorn [l], Marie Hornberger [m], Alexander Finger [n], Nicolai ter Horst [o], Stefanie Peter [p], Erik Kremser [q], Steffen Ciprina [r], Johannes Huwer [b,a], Sebastian Becker-Genschow [s]

[a] Chair of Science Education, Thurgau University of Teacher Education, Unterer Schulweg 3, Kreuzlingen, 8280, Switzerland
[b] Chair of Science Education, University of Konstanz, Universitätsstraße 10, Konstanz, 78464, Germany
[c] Institute of Education, Leibniz University Hannover, Im Moore 11, Hannover, 30167, Germany
[d] Institute of Biology and Its Didactics, University of Education Freiburg, Kunzenweg 21, Freiburg, 79117, Germany
[e] Chair of Biology Education, Dresden University of Technology, Zellescher Weg 19, Dresden, 01069, Germany
[f] Department of Biology Education, University of Salzburg, Hellbrunner Straße 34, Salzburg, 5020, Austria
[g] Centre for Science and Technology Education, University of Applied Sciences and Arts Northwestern Switzerland, Hofackerstrasse 30, Muttenz, 4132, Switzerland
[h] Institute for Science Education, University of Bremen, Bibliothekstraße 1, Bremen, 28359, Germany
[i] Faculty of Physics, Physics Education Research, University of Göttingen, Friedrich-Hund-Platz 1, Göttingen, 37077, Germany
[j] Centre for Biology Education, University of Münster, Schlossplatz 34, Münster, 48143, Germany
[k] Department of Chemistry Education, Leibniz Institute for Science and Mathematics Education, Olshausenstraße 62, Kiel, 24118, Germany
[l] Department of Physics and Astronomy, University of Bonn, Nußallee 14–16, Bonn, 53115, Germany
[m] Life Science Education, Technical University of Munich, Arcisstraße 21, München, 80333, Germany
[n] Centre for Teacher Training and School Research, University of Leipzig, Prager Straße 38–40, Leipzig, 04317, Germany
[o] Department of Chemistry Education, Carl von Ossietzky University Oldenburg, Carl-von-Ossietzky-Str. 9–11, Oldenburg, 26129, Germany
[p] Department of Physics Education, University of Augsburg, Universitätsstraße 1, Augsburg, 86159, Germany
[q] Department of Physics, Technical University of Darmstadt, Hochschulstraße 6, Darmstadt, 64289, Germany
[r] Geographical Institute, Ruhr University Bochum, Universitätsstraße 150, Bochum, 44801, Germany
[s] Department of Digital Education with a Focus on Artificial Intelligence, University of Cologne, Herbert-Lewin-Str. 10, Köln, 50931, Germany

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ABSTRACT

Digital technologies can support knowledge acquisition and transfer, documentation of learning outcomes, and self-regulated and collaborative learning. In science education, they are used to scaffold experimentation, to collect and process measurements, and to support learning with simulations and modeling. To use digital technologies in science teaching in ways that promote learning, teachers require digitalization-related competencies and a well-developed *academic self-concept* regarding subject-specific digitalization-related competencies.

However, existing self-report measures are typically domain-general — not aligned with science-specific frameworks such as DiKoLAN (Digital Competencies for Teaching in Science Education; German: Digitale Kompetenzen für das Lehramt in den Naturwissenschaften) — or focus on related but conceptually distinct constructs such as task- and situation-specific *self-efficacy* expectations. To address this gap, we define *DiKoLAN-SK* as a domain-specific academic self-concept regarding digitalization-related competencies for teaching science and develop and validate its corresponding measure, the *DiKoLAN-SK questionnaire*.

The *DiKoLAN-SK questionnaire* enables domain-specific assessment of pre-service science teachers' *DiKoLAN-SK* aligned with the DiKoLAN framework, thereby supporting diagnosis and evaluation in science teacher education. We tested comprehensibility and provided evidence of validity and reliability in a sample of $N = 286$ pre-service teachers from Germany and Switzerland. Confirmatory factor analyses indicate that responses can reliably distinguish the DiKoLAN competency areas and competency levels as well as the four technology-related knowledge facets of the TPACK framework (*Technological Pedagogical Content Knowledge*). Known-groups comparisons (e.g., target school level, number of science subjects) provide additional validity evidence.

* Corresponding author at: Chair of Science Education, Thurgau University of Teacher Education, Unterer Schulweg 3, Kreuzlingen, 8280, Switzerland.
E-mail address: lars.thoms@phtg.ch (L.-J. Thoms).

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1. Introduction

Learning and teaching in science education can be supported in various ways through the use of digital technologies [e.g., 1,2]. Such technologies can facilitate knowledge acquisition, documentation of learning outcomes, self-regulated and collaborative learning, and information search [e.g., 3–6]. In science education in particular, digital technologies are used to scaffold experimentation, to acquire and process measurements, and to support learning with simulations and modeling [e.g., 7–9]. These science-education application contexts correspond to the competency areas later formalized in the DiKoLAN framework [10,11] (Fig. 1). Here, *digital technologies* refers to hardware and software as well as their pedagogically meaningful application, following the technology dimension of the TPACK framework [*Technological Pedagogical Content Knowledge*, 12].

In contrast to the science-specific competency descriptions in the DiKoLAN framework, existing self-report instruments do not offer the level of detail required to map teachers' academic self-concept onto these competency facets (areas and levels) at the construct level. While available measures address related domains and constructs, they typically do not operationalize the DiKoLAN-specific area-and-level structure needed for a DiKoLAN-aligned assessment. Therefore, a domain-specific instrument is needed to assess pre-service science teachers' academic self-concept regarding digitalization-related competencies across DiKoLAN areas and levels [see 13]. Accordingly, we introduce DiKoLAN-SK and the DiKoLAN-SK questionnaire. Here, *DiKoLAN-SK* denotes the psychological construct of academic self-concept regarding digitalization-related competencies for teaching science, whereas the *DiKoLAN-SK questionnaire* refers to its measurement instrument. We develop the *DiKoLAN-SK questionnaire* and provide validity evidence, enabling domain-specific assessment of pre-service science teachers' *DiKoLAN-SK* aligned with the DiKoLAN framework for use in research and teacher education.

1.1. Professional competence and academic self-concept as a basis for the use of digital technologies in science teaching to promote learning

For digital technologies to be used in a way that promotes learning, teachers must possess the necessary knowledge, skills, and competencies [10,14,15]. According to the model of professional competence [16], motivational orientations — such as *self-efficacy expectations* — are necessary alongside professional knowledge, as they influence whether and how knowledge is applied [17,18]. The construct of self-efficacy expectation refers to a person's conviction that they can successfully master certain tasks and achieve certain goals [19]. Self-efficacy expectation can have a significant influence on a person's motivation, commitment, and performance [20]. The *academic self-concept* also plays an important role. It comprises the subjective assessment of one's own abilities, knowledge, and performance in a particular academic field [21]. It can have an impact on self-efficacy expectations [22,23], play a central role in motivation to act [13], and thus influence a person's attitudes, behavior, and performance in the academic field. Academic self-concept is a broader construct than self-efficacy expectations, as it encompasses not only beliefs about one's own abilities but also a person's overall self-image regarding their academic competence [24,25]. Self-concept can be conceptualized hierarchically across levels of specificity [26]: academic self-concept is more general than domain-specific self-concepts, which are more general than situation-specific self-concepts [25]. Academic self-concept is usually measured via self-report questionnaires assessing perceived competence; while self-report measures are also sometimes used as proxies for self-reported knowledge [e.g., 27], self-concept remains distinct from actual knowledge because it captures subjective self-evaluations rather than performance-based competence [e.g., 28]. The academic self-concept of (pre-service) teachers can be operationalized based on models of the underlying knowledge [e.g., 13,29].

In this study, *academic self-concept* refers to a domain-referenced, relatively stable evaluative self-perception of competence (i.e., perceived competence in a defined domain), whereas *self-efficacy* refers to task- and situation-specific expectancy beliefs about successfully performing a particular action [19,24,25]. Accordingly, self-efficacy instruments assess task- and situation-specific capability beliefs and thus target a conceptually distinct construct. Although both constructs are positively related, they differ in their degree of situational specificity, their psychological focus, and their typical measurement and applications [20,24]. To reduce conceptual overlap, we use domain-general competence judgments rather than situation-bound capability statements. Key conceptual and measurement-related differences between academic self-concept and self-efficacy are summarized in Appendix Table B.7.

Probably the best-known model for structuring professional competence in relation to the use of digital technologies in the classroom is the *TPACK model* [30]. The TPACK model is an extension of Shulman's PCK model for Pedagogical Content Knowledge (PCK) [31] and describes media-related knowledge that (pre-service) teachers need in order to stimulate learning-effective media-supported activities in students [32]. The addition of *Technological Knowledge* (TK) creates three new areas of overlap with the original three knowledge and skill areas of the PCK model, Content Knowledge (CK), Pedagogical Knowledge (PK) and Pedagogical Content Knowledge (PCK): *Technological Content Knowledge* (TCK), *Technological Pedagogical Knowledge* (TPK) and *Technological Pedagogical Content Knowledge* (TPACK). TK, TCK, TPK and TPACK thus represent the four explicitly technology-related knowledge areas. While the TPACK model initially operated largely without domain-specific concretization [30], domain- and subject-specific knowledge in the sense of TPACK has increasingly come into focus in recent years [13,33,34]. As this knowledge forms a basis for digitalization-related competencies, corresponding competence frameworks are required that include these facets. While TPACK specifies the technology-related knowledge dimensions (TK, TCK, TPK, TPACK), it does not delineate science-specific competency areas; DiKoLAN provides this domain structure for science education.

Neither TPACK nor DiKoLAN is a psychological theory of the self. Here, both frameworks function as *domain models* that specify the content reference of self-evaluations: TPACK delineates technology-related professional knowledge facets, and DiKoLAN delineates science-specific digital-competency areas and levels. This structured domain description is necessary to operationalize *which facets* of competence respondents evaluate when reporting their self-concept [24–26]. Accordingly, we define academic self-concept here as perceived competence in the facets specified by DiKoLAN (competency areas/levels) and relate these facets to the technology-related TPACK dimensions that underlie them.

Building on these TPACK dimensions, the DiKoLAN framework (*Digital Competencies for Teaching in Science Education*, the abbreviation stems from the German original *Digitale Kompetenzen für das Lehramt in den Naturwissenschaften*) specifies seven science-related competency areas that structure the domain of digitalization-related competencies for science teaching [Fig. 1, [11]]. The competencies in the areas of *Data Acquisition* (DAQ, including the use of sensors and applications to acquire data and obtain measured values, for example, from images or videos), *Data Processing* (DAP, including data processing through filtering, calculations of new variables or statistical analyses) and *Simulation and Modeling* (SIM, including the target- and addressee-oriented use of digital simulations for the cognitive and communication process and reflection on them) are derived specifically for natural science subjects and are distinguished from four more general areas, *Documentation* (DOC, including systematic filing and permanent storage of data), *Presentation* (PRE, including the target- and addressee-oriented use of different digital presentation media and knowledge of their limitations and potential), *Communication/Collaboration* (COM, including the use of digital tools for synchronous or asynchronous work) and *Information*

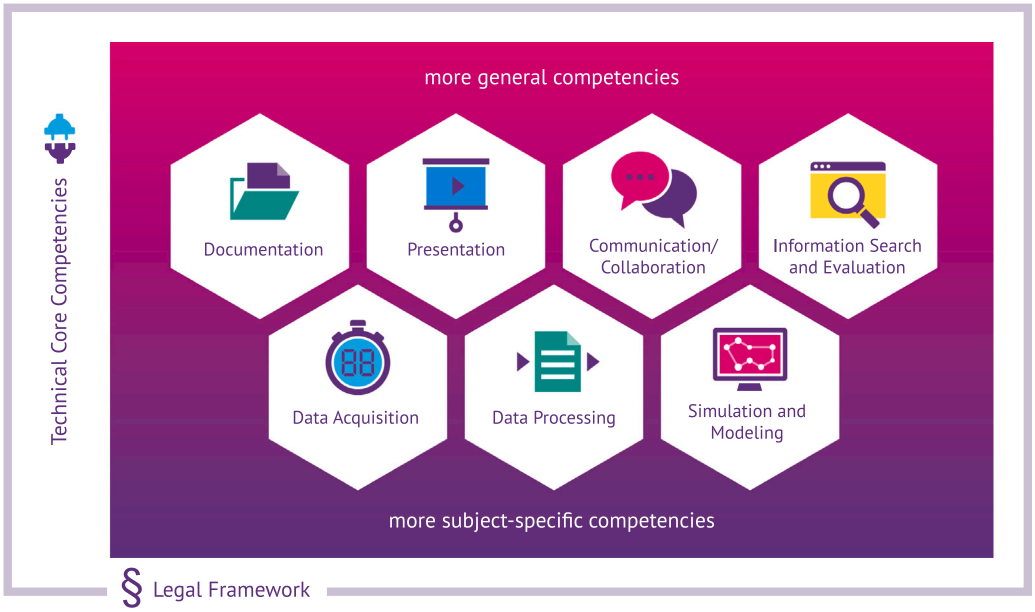

Fig. 1. DiKoLAN framework [11] with seven competency areas for digital competencies in science teaching; this area structure provides the content reference for interpreting DiKoLAN-SK self-concept scores.

Search and Evaluation (ISE, including the procurement, structuring and evaluation of information on given topics using digital tools).

Operationalized competency expectations are formulated for each of the seven central competency areas and are based on the four technology-related dimensions of the TPACK model – *Special tools* (TK), *Content-specific context* (TCK), *Methods, Digitality* (TPK) and *Teaching* [TPACK, see 11] – as well as differentiated into three competency levels – *Name* (N), *Describe* (D) and *Use/Apply* (A) (Fig. 2).

1.2. Research/development status of measurement instruments for digitalization-related skills/competencies

Since the TPACK model was first published, numerous instruments have been developed to measure the TPACK self-concept or the corresponding professional knowledge [Overview in 35–38]. The published instruments have in common that their subscales reflect the TPACK dimensions – either all seven dimensions as individual factors [39] or in some cases several dimensions combined into one factor [e.g., 35,40]. Many authors claim to measure technology-related professional knowledge, although they rather present an instrument to measure the academic self-concept – a problem that has already been highlighted [13, 37]. Furthermore, most instruments are formulated generically, that is, they lack domain specificity in relation to a particular subject [34]. Studies focusing specifically on teachers of a particular subject — for example, physics teachers [41] — generally use non-subject-specific instruments with generically formulated items. The most frequently cited instrument [42], according to Scott [36], possesses inherent subject-specificity and maps the seven TPACK dimensions. In the CK area, the four extracted factors relate to the subject areas “mathematics”, “literacy”, “social studies” and “science” [42, 132], with the latter encompassing all natural science subjects. An instrument for measuring the TPACK self-concept in German-speaking countries, based on the instrument by Schmidt et al. [42], accounts for the domain-specificity of academic self-concept in a given subject (e.g., biology) by incorporating subject-specific items [13]. Domain-specific differentiation beyond the TPACK dimensions has not yet been possible, as no science-specific competence model was available.

However, science subjects require their own subject-specific competencies due to their experimental and technological orientation [10]. In this context, Wilken et al. (2025) recently demonstrated that the integration of technology in the science classroom necessitates distinguishing between a more general and a domain-specific perspective, and they argue that instruments for measuring this specific perspective are lacking [43]. A subject-specific instrument would enable more precise conclusions to be drawn about the academic self-concept regarding the digitalization-related competencies of (pre-service) teachers with regard to their teaching subjects. Academic self-concept data indicate the extent to which (pre-service) teachers perceive themselves as capable of using digital technologies in a didactically sound way in subject teaching; such domain-specific self-perceptions are also positively related to teachers’ self-efficacy, which is important for successful classroom implementation [18,23]. The identification of strengths and weaknesses in relation to a (scientific) subject of study or teaching would enable targeted improvement or professional development. This identification would also facilitate the design and adaptive orientation of measures that would be most relevant and beneficial for (pre-service) teachers. Subject-specific instruments could also be used to track the development of the academic self-concept regarding digitalization-related competencies during the course of study or career progression [14]. This could provide valuable insights into the effectiveness of education and training programs and the impact of corresponding measures. Each subject may require different technological tools and approaches. Subject-specific assessments ensure that teachers are proficient in a variety of tools and strategies, which can help them adapt to the different needs of their learners. Both pre-service [44] and in-service teacher training [45] have shown that subject-specific content relevant to teaching is conducive to improving TPACK and acceptance of digital technologies. For this reason, the present study introduces a science-specific measurement instrument based on relevant competency frameworks and current research and development findings. The article provides insights into the development and validation of this instrument, which is designed to measure the academic self-concept of pre-service teachers regarding digitalization-related competencies in science teaching.

1.3. Evidence of validity for comprehensibility, structure and sensitivity

To capture the academic self-concept of (pre-service) teachers regarding their digitalization-related competencies in science education,

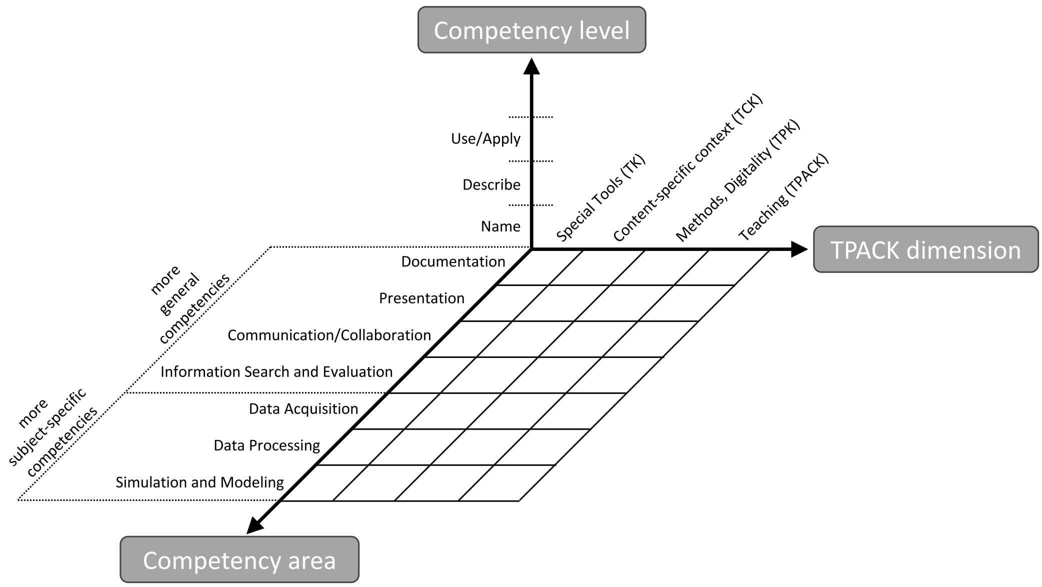

Fig. 2. Conceptual mapping of DiKoLAN competency areas to technology-related knowledge facets (TK, TCK, TPK, TPACK) across the three competency levels of the framework. The DiKoLAN-SK questionnaire operationalizes academic self-concept only for the *Describe* and *Use/Apply* levels; the *Name* level is shown for completeness but was not assessed. This mapping defines the facets respondents evaluate when reporting their domain-specific academic self-concept (DiKoLAN-SK).

a subject-specific measurement instrument — such as the DiKoLAN-SK questionnaire — must be capable of representing this psychological construct. Responses to such a questionnaire should permit conclusions about the academic self-concept of digitalization-related competencies in science education [i.e., *explanatory inference*,46]. Whether such conclusions can validly be drawn is evaluated according to the quality criterion of validity [47]. To determine the validity of explanatory inferences based on the responses, an argument-based approach to validation is applied. This approach formulates testable assumptions about response interpretation and draws on appropriate sources of validity evidence [48].

1.3.1. *Validity evidence for comprehensibility (test content)*

Whether the answers reflect the academic self-concept of digitalization-related competencies depends on the comprehensibility of the questionnaire content for the target group surveyed [i.e., evidence based on *test content*, 47]. In order for the participants' answers to reflect their DiKoLAN-related academic self-concept in the questionnaire, (unavoidable) technical terms in the item wording must be understood by the respondents. In order to formulate items as similarly as possible across the competency areas, the items of a competency area should each be preceded by a target-group-oriented definition of the competency area and an introductory explanation of the essential content and terms (concepts) as the item stem (see Tables D.20–D.26 in the appendix).

1.3.2. *Validity evidence for internal structure*

A confirmatory factor analysis can be used to test whether the answers reflect the academic self-concept on the assumed dimensions of seven competency areas, two competency levels [10] and the four TPACK knowledge facets [30] based on the internal structure [i.e., evidence based on *internal structure*,47]. In addition, the assumption of a hierarchical level of competencies should be tested by setting item difficulty for questions on *application* higher than for questions on *description* and for questions on *teaching implementation* higher than for questions on *teaching planning*.

1.3.3. *Validity evidence for known-groups sensitivity*

Whether the answers in the questionnaire reflect the academic self-concept of digitalization-related competencies taught in science teacher education can be determined by comparing known groups [i.e., evidence based on *known groups*,47]. The comparison of known groups is used to test the sensitivity of the questionnaire to learning opportunities, for example, with students who study different numbers of science subjects. Studies have shown that students majoring in two science subjects benefit from increased learning opportunities in terms of their skills [49], although this has not yet been shown for digitalization-related competencies [13].

The answers in the questionnaire reflect a change in academic self-concept due to learning opportunities during the course of study if students show a higher self-concept in advanced phases of education. Previous studies have only been able to demonstrate a progression through the training phases for the non-technology-specific facets [50, 51], but not for the technology-specific ones, since it is assumed that the learning opportunities in these areas were rather limited in all groups at the time of the survey [13].

Furthermore, the questionnaire's sensitivity to learning opportunities can also be examined with respect to the target school level (i.e., teacher training), as teacher education programs for primary, lower secondary, and upper secondary levels offer varying numbers of learning opportunities [52]. Previous studies indicated that a higher target school level is positively correlated with the development of corresponding professional knowledge and domain-specific academic self-concept [13,50–54]. We assume that the higher the target level, the more — and the more in-depth — learning opportunities are available during the course of study.

1.4. *Aim and research questions*

The aim of this study is to develop and validate the *DiKoLAN-SK questionnaire* as a science-specific instrument to measure *DiKoLAN-SK*, i.e., the academic self-concept of digitalization-related competencies aligned with the DiKoLAN framework. We use DiKoLAN to define the domain-specific construct space and generate items, and we use the TPACK framework as a complementary lens to examine how items relate to technology-related knowledge facets. We provide multi-source validity evidence (comprehensibility, internal structure, sensitivity) and implementation details supporting transparent reuse.

Importantly, this study validates score interpretations of a self-report measurement instrument (DiKoLAN-SK questionnaire) and does not evaluate the educational effectiveness of specific teacher-education interventions. Any statements about learning opportunities refer to plausible group differences (known-groups validity evidence) in our cross-sectional data, not to causal effects.

Overall, the *DiKoLAN-SK questionnaire* provides a validated, domain-specific measure of pre-service teachers' *DiKoLAN-SK* across the competency areas and levels specified by DiKoLAN, thereby supporting diagnosis and evaluation in science teacher education.

With regard to validity evidence, the following research questions will be addressed:

RQ 1: To what extent are the instructions, the definitions of the competency areas, the item stems (for the competency areas in DiKoLAN), and the item texts (for the competency expectations in DiKoLAN) formulated in a way that is understandable for pre-service teachers? *(Comprehensibility/test content)*

RQ 2: Can the seven competency areas (*sensu* DiKoLAN), four foci (*sensu* TPACK), and two competency levels for academic self-concept regarding digitalization-related competencies be empirically separated; and are higher competency levels perceived as more difficult? *(Internal structure)*

RQ 3: Is the academic self-concept of digitalization-related competencies more pronounced among pre-service teachers who (a) study a greater number of science subjects (0 vs. 1 vs. 2), (b) are in a more advanced stage of their education (bachelor's vs. master's program), or (c) are in training to teach at a higher school level (primary, lower secondary, or upper secondary)? *(Known-groups sensitivity)*

2. Methods

2.1. Study design

Pilot testing was conducted as a cross-sectional, questionnaire-based, anonymous paper-and-pencil survey with pre-service teachers in science and general studies. Comprehensibility was additionally examined in a follow-up survey with a second sample. Convenience samples were collected during science education seminars at 12 universities in Germany and Switzerland (within the first four weeks of the winter semester 2022/23 for the pilot study and during the summer semester 2024 for the follow-up). Participation was voluntary and no incentives were offered. Recruitment and administration were organized by members of the research project in collaboration with seminar lecturers. Because recruitment was seminar-based and non-random, the sample is not statistically representative of the population of pre-service science teachers. However, the multi-site setting across two countries and diverse program types (bachelor's, master's, state examination, alternative certification) increases contextual heterogeneity, supporting the *transferability* of findings to comparable teacher-education contexts.

There was no prior intervention, but participants received a short briefing (written information on aims and procedures, legal aspects including informed consent, and intended benefits for teacher education). Each competency area, including comprehensibility items, took about four minutes (about 28 min in total). To reduce sequence and fatigue effects, general and subject-specific competency areas alternated, and participants were randomly assigned to one of two competency-area sequences. In addition, we recorded age, gender, high school graduation grade, university, target school level, subjects studied, preferred teaching subject, training phase, and semester of study as potentially relevant variables for questionnaire comprehension and the development of digitalization-related competencies.

2.2. Sample

During the winter semester of 2022/23, $N = 286$ teacher students from twelve universities and universities of teacher education in Germany and Switzerland participated in the study. Among them were 183 women and 101 men (2 did not specify their gender), with a mean age of $M = 23.8$ years (SD = 5.5). Participants reported studying the following subjects (multiple responses possible): $n_{\text{bio}} = 157$ biology, $n_{\text{che}} = 37$ chemistry, $n_{\text{phy}} = 44$ physics, $n_{\text{geo}} = 42$ geography, and $n_{\text{se}} = 31$ special education. The intended teaching degrees included: $n_{\text{BA}} = 71$ bachelor's degree, $n_{\text{MA}} = 83$ master's degree, $n_{\text{StEx}} = 109$ state examination, and $n_{\text{ac}} = 21$ alternative certification for career changers in Saxony. Participants were enrolled in teacher education programs qualifying them to teach at the following types of schools (multiple responses possible): $n_{\text{GS}} = 121$ primary school, $n_{\text{MS}} = 41$ middle school, $n_{\text{RS}} = 55$ intermediate secondary school, $n_{\text{Gym}} = 52$ academic-stream secondary school, $n_{\text{BS}} = 151$ vocational school, $n_{\text{FS}} = 21$ special education school, $n_{\text{other}} = 43$ other types. The highest intended teaching level reported was: $n_{\text{prim}} = 56$ primary level, $n_{\text{lsec}} = 61$ lower secondary level, $n_{\text{usec}} = 161$ upper secondary level. Nine participants exhibited response patterns suggestive of invalid data (e.g., clearly random or repetitive answers). These cases were excluded from further analyses. Accordingly, the analytic sample comprised $N = 277$ participants. Because recruitment occurred within intact seminar sessions, a formal response rate cannot be computed. For confirmatory factor analyses (CFA), item-level missingness required complete responses on all CFA items; therefore, all CFA models were estimated on a complete-case subsample of $n = 178$. Unless otherwise stated, non-CFA analyses are based on the full analytic sample ($N = 277$).

In a subsequent step, the comprehensibility of the instrument was examined following marginal revisions. During the summer semester of 2024, $N = 50$ pre-service teachers from seven universities in Germany participated in this study. Among them were 28 women and 21 men, with a mean age of $M = 24.4$ years (SD = 3.0). Participants reported studying the following subjects (multiple responses possible): $n_{\text{bio}} = 15$ biology, $n_{\text{che}} = 21$ chemistry, $n_{\text{phy}} = 24$ physics. The degrees aspired to were: $n_{\text{BA}} = 18$ bachelor's degree, $n_{\text{MA}} = 19$ master's degree and $n_{\text{StEx}} = 10$ state examination. Participants were enrolled in teacher education programs qualifying them to teach at the following types of schools (multiple responses possible): $n_{\text{MS}} = 7$ middle school, $n_{\text{RS}} = 4$ secondary school, $n_{\text{Gym}} = 34$ grammar school, $n_{\text{BS}} = 10$ vocational school, $n_{\text{FS}} = 1$ special education school, $n_{\text{other}} = 9$ other types. The highest intended teaching level reported was: $n_{\text{prim}} = 14$ primary education, $n_{\text{lsec}} = 2$ lower secondary education, $n_{\text{usec}} = 34$ upper secondary education.

2.3. Instruments

The questionnaire comprised a demographic section, the newly developed DiKoLAN-SK questionnaire, and an additional component to assess the comprehensibility of individual questionnaire sections–particularly the item stems and item texts.

2.3.1. Short questionnaire on the academic self-concept of digitalization-related competencies for teaching in science education – DiKoLAN-SK

To measure the DiKoLAN-related academic self-concept, the competency expectations formulated in DiKoLAN were converted into competency formulations in the form of "I can..." statements (Fig. 3). Agreement with the skill formulations was measured using an eight-point rating scale (1 — *I cannot do this at all* to 8 — *I can do this perfectly*). A symmetrical scale was chosen to avoid neutral answers, and eight levels were used in order to obtain sufficient resolution and not to use six levels reminiscent of school grades [see 55]. Based on log data from a separate online administration of the finalized questionnaire (not the paper-and-pencil pilot), median completion time was approximately 9–10 min (median = 9.1 min, interquartile range (IQR) = 6.3–12.5 min); very short or very long sessions likely reflect

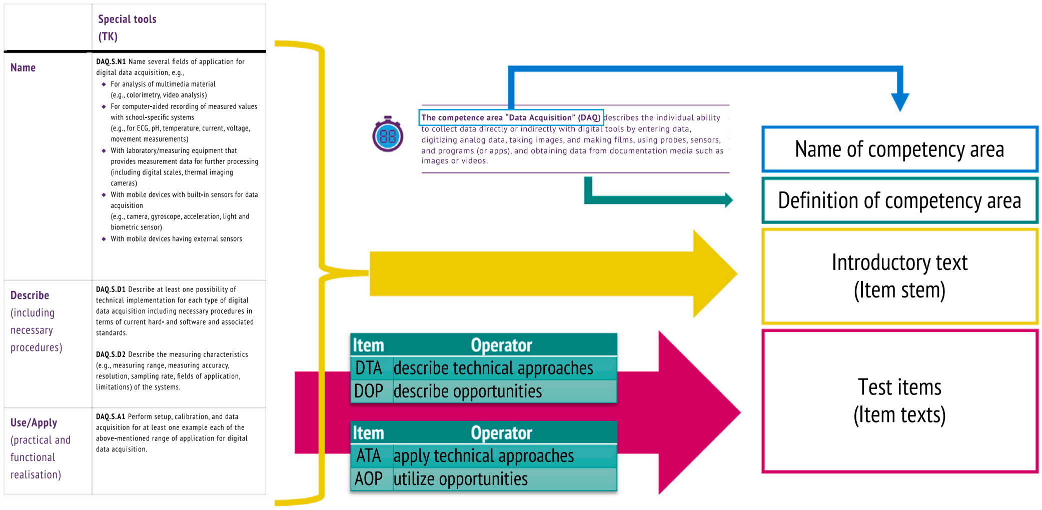

Fig. 3. Overview of how the DiKoLAN competency descriptions [11] are reflected in the questionnaire format: area introductions provide a shared interpretation frame, and items capture perceived competence at different facets. This design supports comparable self-concept judgments across competency areas.

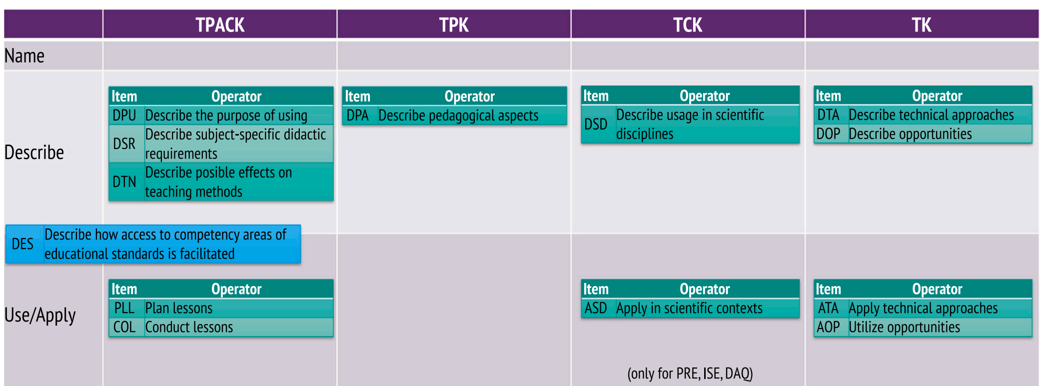

Fig. 4. Coverage of the instrument across DiKoLAN competency areas, TPACK facets, and competency levels. The item set spans the intended construct space, enabling scores to be interpreted both by science-specific competency areas and by technology-related knowledge facets.

speeding or breaks. For scoring, item responses (1–8) can be aggregated as mean scores across predefined item sets by DiKoLAN competency area and competency level. Higher scores indicate a higher DiKoLAN-SK. The item-to-scale mapping and scoring templates are provided in the supplementary XLSX/CSV files and the Visual Scoring Guide. While TPACK facets are used as an analytic lens to describe and compare item foci, the instrument is not intended to be administered as separate TPACK subtests. If a shorter administration is needed, we recommend administering complete DiKoLAN competency areas (i.e., all items belonging to a given area).

For each of the seven competency areas of DiKoLAN (Fig. 1), one to two items were developed for each of the four technology-related knowledge areas according to the TPACK model and for the competency levels *Describe* and *Use/Apply* (Fig. 2), so that each of the 56 (7 × 4 × 2) possible combinations is represented by one to two items, with the exception of the competency level *Use/Apply* in the focus area *Content-specific context* (TCK), which is only planned in the competency areas *Presentation* (PRE), *Information Search and Evaluation* (ISE) and *Data Acquisition* (DAQ) in the framework DiKoLAN (Fig. 4). The competency level *Name* was deliberately not included in order to keep the scope of the questionnaire as small as possible and because excessively high mean feature scores and thus ceiling effects are to be expected here. Overall, the measurement instrument comprises 80 items.

Since DiKoLAN incorporates access to competency areas defined in the educational standards of the German Standing Conference of Ministers of Education and Cultural Affairs of the Länder [KMK] for the intermediate school leaving certificate in biology, chemistry, and physics [56–58] as key practical teaching competencies within the TPACK area, seven items related to the standards were included for the German context. However, these items were excluded from further analysis due to their exclusive reference to the German education system. All items and informational texts were written in German. The English translation of the questionnaire was only used for publication purposes and not in the survey itself (see Appendix D for details).

For administration, we provide ready-to-administer downloads in the online Supplementary Materials: (a) formatted PDFs (German original; English translation) and (b) LimeSurvey import files (.lss) for both languages. In addition, machine-readable instrument files (XLSX/CSV; German original and English translation) including item codes, competency-area assignments, and item-stem/context blocks, as well as a Visual Scoring Guide describing scoring and implementation, are provided to support replication and reuse. Appendix B documents the final validated German wording and Appendix C the English translation for transparency; neither appendix is formatted for direct data collection. All materials (questionnaire files, item lists, and scoring guide) are provided in the online Supplementary Materials under a CC BY-SA 4.0 license (see Data and materials availability).

2.3.2. Supplement to the questionnaire to determine the comprehensibility of the item texts

To ensure that both the introductory explanations and the item texts are formulated in a way that the target population can understand, questions about comprehensibility (e.g., "Is this introductory explanation of the competency area comprehensible to you?") and a comment option ("No, because…") were added to the pilot questionnaire. In addition, the test subjects were asked to mark all examples/techniques/methods that they did not know and therefore could not understand and explain by underlining and circling any individual words that they did not understand.

After revision, the adapted questionnaire was used in a follow-up survey to check the comprehensibility of the text passages revised. In order to not place an excessive burden on the test persons, the revised text passages were highlighted in color and the participants were instructed to evaluate only the comprehensibility of the marked text passages.

2.4. Statistical analyses

Analyses were conducted on the analytic sample ($N = 277$) after excluding cases with response patterns suggestive of invalid data. Item-level missing responses occurred; therefore, the effective sample size varies by analysis. In particular, all confirmatory factor analyses (CFA) were estimated using listwise complete cases on the respective CFA item set (resulting in $n = 178$ for the CFA models reported). Because our main analyses used complete-case estimation, neither imputation nor full-information maximum likelihood (FIML) was applied. The analysis was carried out in three steps: testing a) comprehensibility, b) assumed competence structures and c) comparison of known groups. Statistical analyses were carried out using *R* [59] (see Appendix Table B.8 for software and package versions).

2.4.1. Validity evidence for comprehensibility (test content)

Item stems and item texts were checked if less than 95% of the participants stated that they had understood the help text or the item. Individual words were checked if they were marked in more than 50% of these cases.

2.4.2. Validity evidence for internal structure

Confirmatory factor analyses (CFA) were conducted using the `cfa` function from the *lavaan* package [60,61] and WLSMV (*weighted least squares means and variance adjusted estimator*). Given the high number of indicators and parameters in the 80-item CFA models, the CFA results should be interpreted primarily as evidence for comparative discrimination between competing measurement models (e.g., 1- vs. 2- vs. 7-factor solutions) rather than as highly precise population parameter estimates in this sample.

To assess model fit, both global fit indices (i.e., the ratio of the adjusted chi-square to the model-specific degrees of freedom, X^2_{adj}/df; *Root-Mean-Square Error of Approximation* [RMSEA]; and *Standardized Root Mean Residual* [SRMR]) and incremental fit indices (i.e., *Comparative Fit Index* [CFI] and *Tucker-Lewis Index* [TLI]) are reported. These indices are used both for general model evaluation and for comparative purposes across models. However, we refrain from interpreting them based on strict cutoff criteria [62]. RMSEA 90% confidence intervals (robust/scaled-shifted) were obtained with `fitMeasures` in *lavaan* (reporting `rmsea.robust` and its CI bounds), following common structural equation modeling (SEM) reporting conventions in which RMSEA intervals are typically reported at the 90% level [e.g., 61,63]. Explained variances (R^2) for observed indicators were extracted from the standardized solution and summarized as ranges for the final models. To control for multiple comparisons, we adjusted p-values within each set of pairwise tests using the Benjamini–Hochberg false discovery rate (FDR) procedure [64] ($q = .05$).

2.4.3. Scoring and scope of score interpretations

Responses are recorded on an eight-point scale (1 = *I cannot do this at all* to 8 = *I can do this perfectly*). For each subscale (DiKoLAN competency area or TPACK focus), we compute the mean of the associated items; higher scores indicate a stronger, domain-specific academic self-concept. In this study, reporting and inferential analyses used complete cases for the variables required in each analysis. For applications, we recommend computing a subscale score only when at least 50% of its items are answered. A step-by-step *Visual Scoring Guide* (multi-page PDF) describing scoring, implementation, and interpretation is provided in the online Supplementary Materials.

Scores are indicators of *academic self-concept* regarding digitalization-related competencies; they are not measures of achievement or declarative or procedural knowledge, nor do they provide performance-based evidence of actual digital competence. Moreover, the instrument is aligned with the DiKoLAN framework in its current form and therefore does not cover AI-specific competencies (e.g., generative-AI tools, prompt engineering, or AI-related extensions such as DiKoLAN AI/DiKoLAN PLUS). Supported by the results of the CFA described in the previous subsection, area- and focus-level scores can be used for (i) within-profile interpretations across the seven DiKoLAN areas and (ii) average group comparisons relevant to teacher education (as implemented in the subsequent sensitivity analyses). Scores are not designed for high-stakes or individual decisions; no norms or cut scores are provided.

2.4.4. Validity evidence for known-groups sensitivity

Because the data were not normally distributed, non-parametric alternatives to multivariate analysis of variance (MANOVA) and analysis of variance (ANOVA) were carried out using permutation tests (Euclidean distances, 999 permutations) [65,66] with the `adonis2` function of the *vegan* package [67]. The partial omega squared ω_p^2 was calculated as the effect size using the function `adonis_OmegaSq` from the *MicEco* package (version 0.9.19) [68]. For all families of multiple tests, p-values were adjusted using the Benjamini–Hochberg false discovery rate (FDR) procedure [64] ($q = .05$). Corresponding significance corrections were administered in pairwise comparisons with the package *pairwiseAdonis* [69]. For comparisons of the means of individual dependent variables, Kruskal–Wallis tests [70] were carried out and, in case of significance, post-hoc Dunn tests [71] using the function `dunn.test` from the *dunn.test* package (version 1.3.6) [72]. As effect sizes for Kruskal–Wallis tests, we calculated E_H^2 [measure of association, 0 – no association, 1 – perfect association,73] [74]. For Dunn's test, Cliff's dominance statistic δ [75] was calculated using the `multiVDA` function of the *rcompanion* package (version 2.4.36) [76]. According to Vargha and Delaney [77], effect sizes of $\delta \in [0.11, 0.28)$ can be interpreted as small, $\delta \in [0.28, 0.43)$ as medium, and $\delta \in [0.43 - 1.00]$ as large. For ω_p^2 and E_H^2, we report point estimates and interpret magnitudes in context rather than applying universal cutoffs. For each known-groups comparison, cases with missing values on the variables required for that analysis were excluded.

3. Results

Results follow the analysis plan described in Section 2.4 and are organized by the three research questions and corresponding sources of validity evidence. We first report evidence based on test content (comprehensibility; RQ1). We then examine evidence based on internal structure (RQ2), testing whether DiKoLAN competency areas, TPACK-related foci, and competency levels are empirically separable and show the expected difficulty ordering. Finally, we report evidence based on known-groups comparisons (RQ3) to assess whether DiKoLAN-SK scores differentiate groups that plausibly differ in opportunities to learn.

Table 1
Overview of the comprehensibility of the introductory texts with comprehensibility scores below 95%.

Part of introductory text (Item stem)	DOC	PRE	COM	ISE	DAQ	DAP	SIM
Technical approaches	87.82%				90.18%		93.75%
Opportunities	94.85%				94.89%		93.31%
Scientific references	92.83%		87.50%	91.48%	94.12%	85.66%	
Pedagogical aspects							93.75%

Note: DOC: Documentation; *PRE*: Presentation; *COM*: Communication/Collaboration; *ISE*: Information Search and Evaluation; *DAQ*: Data Acquisition; *DAP*: Data Processing; *SIM*: Simulation and Modeling.

3.1. Validity evidence for comprehensibility (test content)

We begin by reporting evidence on comprehensibility/test content because item interpretation is a prerequisite for meaningful score interpretations (RQ1). The instructions for completing the questionnaire were understood by a large proportion of the students (i.e., > 95%). However, 7.8% and 8.9% of the participants, respectively, stated that they did not find the definitions of the competency areas *Information Search and Evaluation* and *Simulation and Modeling* understandable. In the first case, ten students marked the words "(digitalization-related) quality criteria [*orig.* (digitalisierungsbezogene) Qualitätskriterien]" as incomprehensible. However, two of them noted that the definition follows further down in the questionnaire and that this then contributes to comprehension. In the description of the competency area for *Simulation and Modeling*, the term "computer-aided modeling [*orig* computergestützte Modellierung]" was marked as incomprehensible three times and "scientific inquiry [*orig.* Erkenntnisgewinnungsprozess]" twice. For the other competency areas, the descriptions were understandable for more than 95% of the students.

With the exception of a few problem areas, more than 95% of the students understood the item stems in all competency areas. Nevertheless, comprehension difficulties do arise in isolated text passages (Table 1), which are mainly related to technical terms used (e.g., regarding the *scientific disciplines*). In three competency areas, comprehension difficulties can be seen in the *technical approaches* and *opportunities*. In each case, individual terms were frequently marked as unknown. In only one competency area were the sections on pedagogical aspects marked as understandable by less than 95% of the students. In the competency area of *Data Processing*, the *technical approaches* were considered understandable by more than 95% overall.

The comprehensibility test of the item texts (see Fig. 4 and questionnaire in appendix: Tables D.20–D.26) showed that a total of six items were incomprehensible to more than 5% of the students. Occasionally, the terms "technical approaches [*orig.* Technische Ansätze]", "subject-didactic prerequisites [*orig.* fachdidaktische Voraussetzungen]" and "scenarios [*orig.* Szenarien]" were marked as incomprehensible.

After the problematic text passages had been revised (see Table B.9 in the appendix), a follow-up survey of comprehensibility yielded the following results: For the five text passages from the competency areas of *Data Acquisition* and *Simulation and Modeling*, the comprehensibility is now over 95% in each case; for the five text passages from the competency areas of *Documentation*, *Communication/Collaboration* and *Data Processing*, it is still under 95%. This result is in line with expectations in the areas of *Documentation* and *Data Processing*, since the terms "version control", "gene sequences" and "spectral data" or "concentration measurements" and "colorimetry" were marked again here but cannot be dispensed with due to their central importance. In the area of *Communication/Collaboration*, the introduced explanatory term "computing power" is not understood by some people.

3.2. Validity evidence for internal structure

Next, we test whether the hypothesized dimensionality and competency-level structure are empirically supported (RQ2). In a confirmatory factor analysis, models with seven (according to DiKoLAN competency areas), two (more general and more subject-specific competency areas) and one (no differentiation of areas) factors were tested with regard to the competency areas (Table 2). By successively adding one or five factors, respectively, the modeling predicts the observations statistically significantly better in each case. The model fit indices clearly support the seven-factor structure as the final validated model, which also explains a substantial proportion of item response variance (R^2 = .38 … .85). The internal consistency of the competency areas is very good (Cronbach's α = .92 … .96, M = .94, SD = .02). Robust absolute fit indices further underscore the model fit (RMSEA = .05, 90% CI [.05, .06]; CFI = .98; TLI = .98; SRMR = .08).

As the DiKoLAN framework specifies domain-specific digitalization-related competencies and TPACK distinguishes their pedagogical and technological components, a complementary analysis was conducted to assess whether the items also align with TPACK dimensions. Table 3 shows the model fit indices for the models with four (according to TPACK), two (TPACK/TPK + TCK/TK) and one (no area distinction) factor(s). By successively adding one or two factors, the modeling predicts the observations statistically significantly better in each case (Table 3). The model fit indices also show that the model with four factors fits the data best. The internal consistency of the focal points according to the TPACK model is very good (Cronbach's α = .85 … .97, M = .92, SD = .05). Robust absolute fit indices likewise indicate acceptable fit for the four-factor TPACK model (RMSEA = .09, 90% CI [.08, .09]; CFI = .95; TLI = .95; SRMR = .11). The model-based explained variances indicate good explanatory power across items (R^2 = .24 … .67); on average they were lower than in the DiKoLAN model (R^2_{DiKoLAN} : M = .61, SD = .11; R^2_{TPACK} : M = .46, SD = .12), consistent with the more domain-specific nature of DiKoLAN compared to the more integrative TPACK dimensions.

In a final step within RQ2, we test whether the two intended competency levels (*Describe* vs. *Use/Apply*) can be modeled as distinct factors and whether responses follow the expected ordering in perceived difficulty. Table 4 shows the model fit indices with regard to the competency levels for the models with two (according to DiKoLAN) and one (no level differentiation) factor(s). By adding one factor, the modeling predicts the observations statistically significantly better. The model fit indices also show that the model with two factors fits the data better. Robust absolute fit indices indicate acceptable fit for the two-factor level model (RMSEA = .09, 90% CI [.08, .09]; CFI = .95; TLI = .95; SRMR = .11). The model-based explained variances indicate adequate separation at the level dimension (R^2 = .24 … .67). In 14 out of 17 item pairs, students rate their own competencies at the *Use/Apply* level of competence lower than at the *Describe* level of competence (statistically significant in ten of them; Table B.10).

Across the three sets of model comparisons (DiKoLAN competency areas, TPACK foci, and DiKoLAN competency levels), the respective multi-factor models showed better relative fit than the corresponding more parsimonious alternatives; Table 5 summarizes the preferred models and key fit indices.

The items for *Teaching lessons* are more difficult in all competency areas except *Documentation* and *Data Acquisition* than the corresponding items for *Planning lessons* (Table B.11).

3.3. Validity evidence for known-groups sensitivity

Finally, we examine whether DiKoLAN-SK scores differentiate groups expected to vary in opportunities to learn, as evidence of known-groups sensitivity (RQ3).

Table B.12 provides the descriptive statistics (means and standard deviations) for all group comparisons reported in this section.

Table 2
Confirmatory factor analysis. Model fit indices of the models with 1, 2, or 7 factors and χ^2 difference tests of the models with 1, 2, or 7 factors to discriminate the competency areas according to DiKoLAN. This table reports validation analyses (CFA) and does not contain instrument items; the validated instrument is provided in Appendix B/Appendix C.

Model	Df	χ^2_{adj}	$\frac{\chi^2_{\text{adj}}}{df}$	CFI	TLI	RMSEA	SRMR	χ^2	$\Delta\chi^2$	Δdf	$p(>\chi^2)$
Model 1 (7-factor)	3059	3762.56	1.23	0.98	0.98	0.05	0.08	2442.20			
Model 2 (2-factor)	3079	4128.60	1.34	0.97	0.97	0.07	0.10	3929.82	110.40	20	< 0.001***
Model 3 (1-factor)	3080	4691.41	1.52	0.95	0.94	0.09	0.12	5616.39	44.62	1	< 0.001***

Note: Df: Degrees of freedom; χ^2_{adj}: adjusted χ^2; *CFI*: Comparative Fit Index; *TLI*: Tucker-Lewis Index, *RMSEA*: Root-Mean-Square Error of Approximation, *SRMR*: Standardized Root Mean Residual.

Table 3
Confirmatory factor analysis. Model fit indices of the models with 1, 2, or 4 factors and χ^2 difference tests of the models with 1, 2, or 4 factors to discriminate the focal points according to TPACK dimensions.

Model	Df	χ^2_{adj}	$\frac{\chi^2_{\text{adj}}}{df}$	CFI	TLI	RMSEA	SRMR	χ^2	$\Delta\chi^2$	Δdf	$p(>\chi^2)$
Model 1 (4-factor)	3074	4539.14	1.48	0.95	0.95	0.09	0.11	5136.75			
Model 2 (2-factor)	3079	4547.57	1.48	0.95	0.95	0.09	0.11	5184.53	13.85	5	0.0166*
Model 3 (1-factor)	3080	4691.41	1.52	0.95	0.94	0.09	0.12	5616.40	27.94	1	< 0.001***

Note: Df: Degrees of freedom; χ^2_{adj}: adjusted χ^2; *CFI*: Comparative Fit Index; *TLI*: Tucker-Lewis Index, *RMSEA*: Root-Mean-Square Error of Approximation, *SRMR*: Standardized Root Mean Residual.

Table 4
Confirmatory factor analysis. Model fit indices of the models with 1 or 2 factors and χ^2 difference tests of the models with 1 or 2 factors to discriminate the competency levels *Describe* and *Use/Apply* according to DiKoLAN.

Model	Df	χ^2_{adj}	$\frac{\chi^2_{\text{adj}}}{df}$	CFI	TLI	RMSEA	SRMR	χ^2	$\Delta\chi^2$	Δdf	$p(>\chi^2)$
Model 1 (2-factor)	3079	4610.11	1.50	0.95	0.95	0.09	0.11	5327.27			
Model 2 (1-factor)	3080	4691.41	1.52	0.95	0.94	0.09	0.12	5616.39	12.90	1	< 0.001***

Note: Df: Degrees of freedom; χ^2_{adj}: adjusted χ^2; *CFI*: Comparative Fit Index; *TLI*: Tucker-Lewis Index, *RMSEA*: Root-Mean-Square Error of Approximation, *SRMR*: Standardized Root Mean Residual.

Table 5
Summary of preferred CFA models by construct perspective (comparative model evaluation). Summary of validation (CFA) results; not an instrument table. The validated item set is reported in Appendix B/C.

Perspective	Preferred model	χ^2_{adj}/df	CFI	TLI	RMSEA	SRMR
DiKoLAN competency areas	7-factor model	1.23	0.98	0.98	0.05	0.08
TPACK foci	4-factor model	1.48	0.95	0.95	0.09	0.11
DiKoLAN competency levels	2-factor model	1.50	0.95	0.95	0.09	0.11

Note: This table summarizes the best-fitting model within each comparison. Full model-comparison results (including nested χ^2 difference tests) are reported in Table 2, Table 3, and Table 4. Fit indices are reported for comparative evaluation of competing measurement models; we do not interpret them using strict cutoff criteria.

3.3.1. Number of science subjects

Of the complete cases available, $n_{\text{zero}} = 46$ did not take any science subjects, $n_{\text{one}} = 181$ took one science subject, and $n_{\text{two}} = 15$ took two science subjects. The multivariate homogeneity of the group scatter for the scores of the seven competency areas was confirmed ($F(2, 239) = 2.32$; $p = 0.1$), so that a permutation test could be used as a non-parametric MANOVA (according to McArdle & Anderson, 2001, Euclidean distances, 999 permutations). This showed that the groups with zero, one or two science subjects are not equally distributed in all competency areas ($F(1, 240) = 12.70$; $p = 0.001$; $\omega^2_{\text{p}} = 0.05$). Pairwise comparisons show statistically significant imbalances between zero and one subject ($F(1, 241) = 14.67$; $p = 0.003$; $R^2 = 0.06$) and between zero and two subjects ($F(1, 241) = 5.34$; $p = 0.012$; $R^2 = 0.08$). The distributions do not differ significantly between one and two science subjects ($F(1, 241) = 0.43$; $p = 0.7$).

Kruskal–Wallis tests for the individual competency areas showed no statistically significant differences in the mean scores of the respective competency area between the groups with no, one or two science subjects for the more general competency areas. In all subject-specific competency areas, there were statistically significant mean differences between the groups: *Data Acquisition* ($H(2; 242) = 37.68$; $E^2_H = 0.156$; $p < 0.001$), *Data Processing* ($H(2; 242) = 14.11$; $E^2_H = 0.059$; $p < 0.001$) as well as *Simulation and Modeling* ($H(2; 242) = 11.42$; $E^2_H = 0.047$; $p = 0.0033$).

Post-hoc Dunn tests for these three competency areas showed statistically significant differences in the means with large effect sizes between zero and one science subject ($\delta = -0.57$; $p < 0.001$) and between zero and two science subjects ($\delta = -0.664$; $p < 0.001$) for *Data Acquisition* and *Data Processing* with medium ($\delta = -0.346$; $p < 0.001$) or large effect sizes ($\delta = -0.424$; $p = 0.0082$) as well as for *Simulation and Modeling* with medium effect sizes ($\delta = -0.312$; $p = 0.0017$) and ($\delta = -0.372$; $p = 0.018$).

Post-hoc Dunn tests showed statistically significant mean differences for the three subject-specific competency areas. For *Data Acquisition*, scores increased from the group with zero science subjects ($M = 3.75$, SD = 1.54) to one science subject ($M = 5.46$, SD = 1.46) and two science subjects ($M = 5.75$, SD = 1.32), with large effects for zero vs. one ($\delta = -0.57$, $p < 0.001$) and zero vs. two ($\delta = -0.664$, $p < 0.001$). For *Data Processing*, means likewise increased from zero ($M = 4.47$, SD = 1.55) to one ($M = 5.37$, SD = 1.50) and two science subjects ($M = 5.57$, SD = 1.71), with medium to large effects (zero vs. one: $\delta = -0.346$, $p < 0.001$; zero vs. two: $\delta = -0.424$, $p = 0.0082$). For *Simulation and Modeling*, means increased from zero ($M = 4.08$, SD = 1.70) to one ($M = 5.01$, SD = 1.44) and two science subjects ($M = 5.16$, SD = 1.70), with medium effects (zero vs. one: $\delta = -0.312$, $p = 0.0017$; zero vs. two: $\delta = -0.372$, $p = 0.018$).

3.3.2. Study phase

Since the bachelor's and master's programs build on each other, these two programs are considered study phases here. Of the complete cases available, $n_{\text{BA}} = 49$ were in the bachelor's program and $n_{\text{MA}} =$

71 were in the master's program. Multivariate homogeneity of group dispersion across the seven competency-area scores was supported ($F(1118) = 0.97$, $p = .33$), so we used a non-parametric MANOVA via permutation (McArdle & Anderson, 2001; Euclidean distances; 999 permutations). The permutational MANOVA indicated no statistically significant differences between study phases across competency areas ($F(1118) = 0.80$, $p = .44$), with only small descriptive differences between phases.

3.3.3. Target school level

To examine expected differences in academic self-concept in connection with the target school type of the degree program attended, possible assignments to school types (multiple responses were possible) were grouped in such a way that, for several target school levels, the highest target school level (upper secondary > lower secondary > primary) was decisive for the grouping.

The multivariate homogeneity of the group scatter for the scores of the seven competency areas was confirmed ($F(2, 233) = 3.86$; $p = 0.022$). A permutation test at the group level showed that the groups' scores are not equally distributed in all competency areas ($F(1, 234) = 8.02$; $p = 0.001$; $\omega^2_{\mathrm{p}} = 0.03$).

Pairwise comparisons (Kruskal–Wallis tests) for the individual competency areas showed no statistically significant differences between the target levels for the more general competency areas, but statistically significant differences for the more subject-specific competency areas of *Data Acquisition* ($H(2, 236) = 16.58$; $E^2_H = 0.071$; $p < 0.001$), *Data Processing* ($H(2, 236) = 6.82$; $E^2_H = 0.029$; $p = 0.033$), and *Simulation and Modeling* ($H(2, 236) = 11.57$; $E^2_H = 0.049$; $p = 0.0031$).

Post-hoc Dunn tests showed statistically significant mean differences for these three competency areas. For *Data Acquisition*, scores increased from the primary level ($M = 4.12$, SD = 1.68) to lower secondary ($M = 5.19$, SD = 1.74) and upper secondary ($M = 5.39$, SD = 1.44), with very small effects for primary vs. lower secondary ($\delta = -0.06$; $p = 0.0018$) and primary vs. upper secondary ($\delta = -0.046$; $p < 0.001$). For *Data Processing*, means increased from primary ($M = 4.63$, SD = 1.55) to lower secondary ($M = 5.23$, SD = 1.68) and upper secondary ($M = 5.33$, SD = 1.49), with small effects for primary vs. lower secondary ($\delta = -0.222$; $p = 0.038$) and primary vs. upper secondary ($\delta = -0.272$; $p = 0.014$). For *Simulation and Modeling*, means increased from primary ($M = 4.02$, SD = 1.82) to lower secondary ($M = 4.68$, SD = 1.55) and upper secondary ($M = 5.06$, SD = 1.39), with a medium effect for primary vs. upper secondary ($\delta = -0.34$; $p = 0.0013$).

4. Discussion

Building on the need for a science-specific measure of academic self-concept in digitalization-related competencies outlined in the Introduction, this study developed and validated the DiKoLAN-SK questionnaire. Based on the competency expectations formulated in DiKoLAN and informed by prior research on digitalization-related competencies and academic self-concept, we evaluated the extent to which DiKoLAN-SK supports valid and reliable score interpretations regarding the DiKoLAN competency areas and levels. The following sections summarize the resulting validity evidence (comprehensibility, internal structure, and known-groups sensitivity), aligned with RQ1–RQ3, clarify the scope of supported interpretations, and discuss implications for science education research and teacher education.

4.1. Validity evidence for comprehensibility (test content)

Regarding RQ1 (comprehensibility/test content), we summarize the evidence from the cognitive interviews and related analyses, focusing on item and instruction clarity and any terminology-related issues. In the DiKoLAN-SK questionnaire (Tables D.20–D.26 in the appendix), instructions, item stems, and item texts show a consistently high comprehensibility of the digitalization-related technical terms. There were no significant comprehension difficulties with the definitions of the areas of competency, that is, the definitions are already adapted for the target group of students without deviating significantly from the definition in DiKoLAN. No revisions were necessary in the instructions or item texts. The instructions were clearly understood by all pre-service teachers, and item stems provided sufficient context to clarify any potentially unclear item texts. Furthermore, no unexpected deviations were found in the statistical analyses. Occasional comprehension difficulties in the item stems were mainly caused by unfamiliar (but unavoidable) technical terms. Comprehensibility could be further increased by revising only a few incomprehensible technical terms in the item stems. Table B.9 contrasts the original formulations with the adaptations and lists justifications/comments on the adaptations. However, the proportion of subjects without comprehension difficulties is large enough and the proportions of comprehension difficulties per subject are low enough that no subjects have to be excluded from the analyses due to comprehension difficulties. Overall, the proposed adjustments significantly improved the comprehensibility of the questionnaire. However, especially in the scientific contexts, the use of scientific or digitalization-related terms cannot be completely avoided if the described competency areas are to be reliably covered. Since these technical terms only make up a negligible proportion of the total questionnaire, it should be possible to assume that the students are able to assess their academic self-concept in this area with sufficient accuracy, even if they do not understand certain technical terms.

It can be assumed that the slightly revised questionnaire will provide comparable results to the questionnaire used in the first study, so that all the following statements and conclusions regarding the reliability and validity of the measurement also apply to the slightly linguistically revised questionnaire.

4.2. Validity evidence for internal structure

Turning to RQ2 (internal structure), the results support the intended dimensionality of DiKoLAN-SK across competency areas and competency levels, and additionally align with a TPACK-based structuring. The DiKoLAN-SK questionnaire allows conclusions to be drawn about the academic self-concept of digitalization-related competencies in seven competency areas (three more subject-specific areas, *Data Acquisition*, *Data Processing* and *Simulation and Modeling*, and four more general areas, *Documentation*, *Presentation*, *Communication/Collaboration* and *Information Search and Evaluation*) and two levels of competency (*Describe* and *Use/Apply*), since the 7-factor internal structure of the DiKoLAN framework can be mapped in a valid, reliable and empirically separable way in all considered facets (seven competency areas, tiered competency levels *Describe* and *Use/Apply*). Furthermore, the questionnaire allows inferences about academic self-concept regarding digitalization-related competencies in the professional knowledge areas according to the TPACK model [e.g., 13,28], since the internal structure according to the TPACK model could also be empirically confirmed. Thus, the DiKoLAN-SK questionnaire on the one hand reflects the structures found in previous studies [13,28]; for the TPACK model, this corresponds to the findings on TPACK-related academic self-concept [e.g., 13] and on TPACK itself [e.g., 28]. On the other hand, the questionnaire extends previous studies by enabling, for the first time, a differentiation of academic self-concept into more subject-specific and more general competency areas in accordance with the DiKoLAN framework [10]. Furthermore, the assumption is confirmed that *Describe* and *Use/Apply* can be seen as two levels. Only in the competency areas of *Documentation* and *Data Acquisition* are the items for *Conduct lessons* easier than for *Plan lessons*. In the latter case, the additional requirement of "taking into account suitable organizational and social forms [*orig.* unter Berücksichtigung geeigneter Organisations- und Sozialformen]" is missing in *Conduct lessons*. This requirement should be added.

4.3. Validity evidence for known-groups sensitivity

With respect to RQ3 (known-groups sensitivity), the results suggest that DiKoLAN-SK differentiates between groups with differing subject-related learning opportunities in the more subject-specific competency areas, while evidence for more general areas is less conclusive. Consistent with this aim, DiKoLAN-SK captures differences in academic self-concept in the more subject-specific competency areas (*Data Acquisition*, *Data Processing*, *Simulation and Modeling*) as a function of subject-related learning opportunities. However, the study does not provide any validity evidence that allows conclusions to be drawn about how academic self-concept in relation to digitalization-related competencies in more general areas. Future validation studies should account for a more fine grained differentiation of learning opportunities that is not based on the subject area or the target school level [13]. The self-concept regarding the more subject-specific competency areas was significantly higher among students with one or two science subjects than among students without a science subject, with medium or large effect sizes. By contrast, the self-concept regarding the more general competency areas was independent of the number of science subjects and the associated learning opportunities. These findings are in line with expectations in that students with two science subjects showed higher professional competencies in previous studies [49], but not in technology-related competencies [13]. The present questionnaire thus complements previous questionnaires [e.g., 13] by mapping academic self-concept to more subject-specific digitalization-related competencies depending on subject-related learning opportunities.

With regard to learning opportunities in degree programs with different target school levels, a similar picture emerges: Here, too, it can be seen that the questionnaire is sensitive to subject-specific learning opportunities and can accordingly reflect the academic self-concept of more subject-specific digitalization-related competencies. Students with target school levels of lower and upper secondary have a significantly higher self-concept in subject-specific competency areas than students with the target school level of primary. This finding is in line with expectations and comparable to studies that found that students aiming for the secondary level had a higher academic self-concept than students aiming for the primary level due to more learning opportunities [51–54]. However, the finding also extends a previous study that could not find such a sensitivity of a questionnaire on technology-related academic self-concept for learning opportunities [13].

A progression of the self-concept from the bachelor's to the master's program, as previously observed for non-technology-specific majors [e.g., 50,51], cannot be demonstrated as in Mahler and Arnold [13]. Future studies should clarify whether these findings are due to a lack of sensitivity in the questionnaires or to an insufficient number of digitalization-related learning opportunities in the course of study.

4.4. Overall assessment of validity

This study examined which conclusions can be drawn from the DiKoLAN-SK questionnaire about the academic self-concept regarding digitalization-related competencies according to DiKoLAN. The questionnaire is largely comprehensible for all target groups, so that response behavior is not influenced by a lack of comprehensibility. The questionnaire allows conclusions to be drawn about academic self-concept in the TPACK knowledge areas as well as in three more subject-specific and four more general competency areas. The questionnaire is also sensitive to subject-specific learning opportunities and can thus reflect developments in academic self-concept towards more subject-specific digitalization-related competencies. The sensitivity of the questionnaire to subject-specific learning opportunities is an important contribution to previous studies, which predominantly map generic learning opportunities [37]. In contrast to generic instruments on digitalization-related competencies or self-efficacy, the DiKoLAN-SK provides a domain-specific measure of academic self-concept grounded in the DiKoLAN and TPACK frameworks.

4.5. Strengths and limitations

Our study draws its strength from the domain-specific nature of the instrument for measuring academic self-concept. The DiKoLAN-SK questionnaire is among the first science-education–specific academic self-concept instruments explicitly grounded in a domain competency framework (DiKoLAN) and operationalized across framework-defined competency areas and levels. A central theoretical contribution is the integration of academic self-concept theory with DiKoLAN for domain specification and TPACK as a complementary lens to structure technology-related knowledge foci across items. All subscales demonstrated high reliability, and the seven DiKoLAN areas were empirically separable, supporting construct coverage and the intended *score interpretations* for the uses and populations studied. The multi-site sampling across twelve universities in Germany and Switzerland, together with heterogeneous program types, increased variability in relevant learner characteristics and, with an analytic sample of $N = 277$, afforded adequate power for the reported group comparisons; structural model testing via CFA was based on complete cases (see discussion below). From a practical perspective, the instrument is time-efficient and suitable for low-burden cohort-level diagnosis and evaluation (e.g., profiling strengths/needs at the level of specific competency areas and monitoring score changes over time), thereby supporting formative curriculum alignment with science-specific targets (DiKoLAN) and related reference frameworks. Finally, openness and reusability are strengthened by providing comprehensive implementation materials (including a step-by-step Visual Scoring Guide) in the online Supplementary Materials, enabling transparent reuse and reporting.

Besides these strengths, the study has limitations that mainly concern (a) scope and generalizability and (b) measurement and design constraints. First, data were collected in science education seminars, which typically focus on a single subject. It is therefore conceivable that participants anchored their responses in their primary subject without equally considering a possible second science subject (i.e., situated responding). As a result, in this study, the DiKoLAN-SK questionnaire may have captured the academic self-concept of digitalization-related competencies with respect to the reference subject rather than across all subjects studied. These circumstances could also help explain why some assumptions regarding known-group comparisons were not confirmed—particularly those related to progression from the bachelor's to the master's level and to an increasing number of science subjects. The aggregation by school type proved difficult due to differing program structures; we therefore compared by school level instead. In addition, the *Name* level of the DiKoLAN framework was deliberately omitted to reduce respondent burden, so not all framework facets are represented.

Second, the survey conditions do not constitute a true random sample of the target population, which limits the generalizability of the findings to the entire German-speaking area. In particular, no participants from Austria were included. In addition, although the analytic sample comprised $N = 277$, item-level missing responses reduced the effective sample size for the CFA models to $n = 178$ complete cases. Given the complexity of the 80-item instrument and the corresponding model degrees of freedom, the CFA results should therefore be interpreted as preliminary and primarily informative for discriminating competing measurement models (1-, 2-, vs. 7-factor solutions), rather than for establishing population-representative parameter estimates. Replication in larger and more diverse samples (including measurement invariance testing) is needed to strengthen generalizability of the structural findings. The sample size for CFA ($n = 178$ complete cases) also falls short of rules-of-thumb sometimes recommended for highly parameterized models. However, it does meet the general guideline of $N > 100$ as a minimum requirement [78]. Although the sampling strategy focused on two German-speaking countries (Germany and Switzerland), which limits generalizability, this approach ensured comparable cultural and linguistic contexts. Such alignment helped establish a common understanding of the questionnaire items and reduced potential biases arising from translation issues or culturally specific interpretations. While this supports linguistic equivalence, it also limits generalizability to other cultural or linguistic contexts. Despite a careful translation procedure (see Appendix C), minor semantic drift cannot be ruled out; future work should test multi-language measurement invariance.

Methodologically, several caveats apply. Self-report data are susceptible to social-desirability and reference-frame effects; the eight-point forced-choice scale removes neutrality and may shift responses upward. Potential ceiling effects are plausible in the *Presentation* subscale, which showed high means. With 80 items and a complex factor structure, the sample size — while adequate for the WLSMV — still warrants cautious interpretation of small effects. We did not account for clustering of students within courses or institutions, nor did we test measurement invariance across key groups (e.g., gender, country). Furthermore, the cross-sectional design precludes inferences about intra-individual change over time; longitudinal validation and sensitivity-to-change analyses are needed.

Finally, in line with the focus of the DiKoLAN framework, the findings are further limited to pre-service teachers, and future studies should extend validation to in-service populations to examine possible developmental differences.

4.6. Implications for use as a measurement instrument

The DiKoLAN-SK questionnaire is a comprehensible and reliable instrument that supports economical measurement and valid interpretations of scores on academic self-concept in digitalization-related competencies, differentiated according to science-specific competency areas. The questionnaire tested was very comprehensible in German, and the English version was produced via a careful translation process; however, it has not yet been cognitively pretested or validated. The questionnaire is suitable for the measurement of the academic self-concept in all competency areas and is also sensitive to subject-specific learning opportunities, so that resulting changes in DiKoLAN-SK can be measured for the more subject-specific competency areas (e.g., in longitudinal studies as well as site-specific or cross-site cross-sectional studies). Based on our findings, DiKoLAN-SK scores are suitable for diagnostic profiling in teacher education (identifying relative strengths and needs across DiKoLAN areas), group-level evaluation of interventions (e.g., pre-post), and research on the structure and sensitivity of digitalization-related academic self-concept.

The subscales for the individual competency areas are reliable and empirically distinct, allowing for their separate use as needed. On average, each subscale takes about three minutes to complete (excluding the recording of comprehensibility), resulting in a total of approximately 21 min for the entire instrument. Because item difficulties differ across areas, we recommend reporting effect sizes with confidence intervals for comparisons (e.g., Hedges' g, Cliff's δ) and contextualizing raw mean differences. Longitudinal sensitivity has not yet been established; observed changes should be treated as preliminary until confirmed. Our results show sensitivity in the more subject-specific areas (*Data Acquisition*, *Data Processing*, *Simulation and Modeling*) with respect to subject-related learning opportunities (number of science subjects; target school level), but not clear progression from bachelor's to master's. Accordingly, caution is warranted when interpreting phase differences, and such comparisons should be complemented by additional indicators of opportunities to learn.

Scores reflect self-concept and may be influenced by response tendencies (e.g., social desirability; forced-choice scale without a neutral midpoint). Potential ceiling effects (especially in *Presentation*) should be considered. Measurement invariance across subgroups (e.g., gender, country, school level) and clustering effects (courses/universities) were not examined here; between-group inferences should therefore be made cautiously. The instrument is not intended for high-stakes individual decisions; no norms or cut scores are available.

For applications, compute a subscale score only if at least 50% of its items are answered. Use profiles to align teaching responsibilities or support offers across disciplines, but avoid rank-ordering individuals. Where feasible, triangulate self-concept profiles with complementary evidence (e.g., observed performance or coursework artifacts) for programmatic decisions.

4.7. Implications for further research

It remains questionable how attentively students read the questionnaire and, particularly, the competency area definitions and item texts. The significant differences in the answers between the competency areas presumably cannot be attributed solely to the differences in the item texts, which can be interpreted as an indication of attentive reading of the competency area definitions and item stems. Nevertheless, it should be examined (e.g., using eye tracking) whether all parts of the questionnaire are read with sufficient attention.

The present questionnaire can resolve differences in academic self-concept regarding digitalization-related competencies between students with and without science as a teaching subject, but not between students with one and two subjects. Furthermore, the questionnaire cannot resolve differences in academic self-concept regarding digitalization-related competencies between bachelor's and master's degree programs. Future research should examine whether this is due to a lack of sensitivity of the questionnaire or to a comparable number of digitalization-related learning opportunities in one and two science subjects or an insufficient number of digitalization-related learning opportunities. Furthermore, it should be examined whether students tend to refer to teaching in general, to science teaching, or to teaching in the subject in which the survey took place when answering the questionnaire (to an equal extent in all parts of the questionnaire).

In line with the focus on the underlying DiKoLAN framework, the DiKoLAN-SK questionnaire was developed for use in the first phase of teacher education (university studies). Since academic self-concept regarding digitalization-related competencies is no less important in the second and third phases (in-school preparatory training and ongoing professional development, respectively), the suitability of the DiKoLAN-SK questionnaire for these target groups should be examined and the questionnaire should be adapted, further developed, and specifically validated if necessary.

Recent extensions of the DiKoLAN-framework — DiKoLAN PLUS (adding the competency area *Assessment, Feedback and Adaptivity*) [79] and DiKoLAN AI (applying DiKoLAN to artificial intelligence and specifying competencies for teaching *with* and *about* AI) [80] — open clear avenues for instrument development in an AI-shaped digital education landscape. Importantly, because DiKoLAN-SK operationalizes academic self-concept strictly within the construct space defined by the original DiKoLAN framework, AI-related competencies are outside the intended score interpretation supported by the present validity evidence. Consequently, extensions that add new domains or alter the construct space (e.g., DiKoLAN PLUS; DiKoLAN AI) should be treated as scale extensions and require renewed validation; at minimum, evidence based on test content (expert review/cognitive pretesting) and re-examination of internal structure (CFA) is necessary, and substantial extensions warrant full re-validation (including reliability and sensitivity evidence). In contrast, minor contextual adaptations that do not change the construct definition (e.g., wording adjustments for a specific course context) may be supported by targeted, partial checks focused on content and internal structure. Future work should therefore derive and cognitively pretest self-concept items for these extended domains (DiKoLAN PLUS; DiKoLAN AI), examine their internal structure (e.g., separability from existing DiKoLAN areas via CFA), and establish reliability, convergent/discriminant validity, sensitivity to opportunities to learn, and longitudinal sensitivity to change. Measurement invariance across subject areas, phases of teacher education, and countries should be tested before routine use. Multimethod studies linking self-concept in these new areas with observed performance or coursework artifacts, as well as predictive validity (e.g., course choices, practicum behaviors), are likewise warranted.

4.8. Implications for teacher education

The results of the modeling show that the DiKoLAN competency areas represented in the instrument align with existing facets and performance-related components of pre-service teachers' (academic) self-concept. Because the instrument can capture and profile these areas, it can be used formatively for diagnosis and evaluation in university teacher education. When used at a single time point (e.g., at the beginning of the semester), it can support diagnosis: based on their responses by competency area, students can select content for further study in areas where they do not yet feel confident, and lecturers gain an overview of where support is most needed by comparing students' answers across areas. When used at multiple time points (e.g., beginning and end of the semester), changes in scores can be examined to assess the effectiveness of training aimed at promoting digitalization-related competencies. Repeated use provides instructors with insights into how confident their students feel about applying their competencies.

Another positive aspect is the instrument's compatibility, which is evident in several respects. The domain-specific nature of DiKoLAN, combined with the instrument structure that considers TPACK domains, provides a bridge between the two frameworks and supports alignment with both theoretical models and university practice. For example, students' measured profiles can inform the distribution of teaching responsibilities across relevant disciplines and help diagnose strengths and needs at the level of specific competency areas.

Beyond its use within the DiKoLAN and TPACK structures, DiKoLAN-SK also supports monitoring and curricular alignment in teacher education. In particular, repeated administrations (e.g., pre–post within seminars or longitudinally across study phases) can be used to track changes in *academic self-concept* for digitalization-related competencies at the level of science-specific DiKoLAN areas and TPACK-related foci. Because DiKoLAN operationalizes science-education–specific facets that are treated more broadly in overarching competence frameworks such as DigCompEdu [15] and in national policy documents such as the KMK strategy *Bildung in der digitalen Welt* (German: Education in the digital world) [81], DiKoLAN-SK can complement domain-general self-assessment approaches by adding domain-specific resolution for science teacher education [82,83].

5. Conclusion

Due to the urgent need for a science-specific measurement instrument for academic self-concept in digitalization-related competencies, we developed and validated the DiKoLAN-SK questionnaire for German-speaking teacher education in science. The instrument enables differentiated interpretations of academic self-concept across seven DiKoLAN competency areas, two competency levels, and four TPACK-related foci, thus providing more domain-specific resolution than previously available measures.

In addition, DiKoLAN-SK can serve as a low-burden tool to track changes in digitalization-related academic self-concept scores over time (e.g., pre–post within seminars or longitudinally across study phases) and to support formative alignment of learning opportunities with both science-specific targets (DiKoLAN) and broader reference frameworks such as DigCompEdu and the KMK strategy *Bildung in der digitalen Welt* [15,81–83].

Overall, this study provides a validated instrument that enables research and practice to capture *academic self-concept* in digital teaching contexts specifically within science education. Importantly, DiKoLAN-SK assesses self-perceptions rather than actual (performance-based) digital competence, and it is not intended to capture AI-specific skills.

While the construct is theoretically anchored in internationally established work on academic self-concept and TPACK, the present validity evidence is limited to German-speaking teacher education contexts (Germany/Switzerland) and German-language administration. To facilitate international reuse, we provide an English-language version based on a careful translation procedure; however, this version has not yet been validated. Accordingly, any use beyond the validated German-speaking contexts — including administration of the English version — should be accompanied by renewed validation (e.g., cognitive pretesting, re-examination of internal structure, and measurement invariance testing) before cross-context comparisons are made.

CRediT authorship contribution statement

Lars-Jochen Thoms: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Till Bruckermann:** Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis, Conceptualization. **Christoph Thyssen:** Writing – original draft, Resources, Methodology, Investigation, Funding acquisition, Formal analysis. **Monique Meier:** Methodology, Conceptualization. **Lena von Kotzebue:** Writing – review & editing, Methodology, Conceptualization. **Julia Arnold:** Writing – original draft, Resources, Investigation. **Nadja Belova:** Writing – original draft, Resources, Investigation, Conceptualization. **Simon Z. Lahme:** Writing – review & editing, Resources, Investigation. **Benedikt Heuckmann:** Resources, Investigation, Conceptualization. **Stefanie Lenzer:** Resources, Investigation. **Bernadette Schorn:** Writing – review & editing, Resources, Investigation. **Marie Hornberger:** Writing – review & editing, Resources, Investigation, Conceptualization. **Alexander Finger:** Writing – review & editing, Resources, Methodology, Investigation, Conceptualization. **Nicolai ter Horst:** Writing – review & editing, Resources, Investigation, Conceptualization. **Stefanie Peter:** Writing – original draft, Resources, Investigation, Conceptualization. **Erik Kremser:** Writing – review & editing, Methodology, Conceptualization. **Steffen Ciprina:** Resources, Investigation, Conceptualization. **Johannes Huwer:** Writing – review & editing, Methodology, Conceptualization. **Sebastian Becker-Genschow:** Writing – review & editing, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Ethics statement

The study involved a voluntary survey of adult participants. All participants provided informed consent after receiving detailed information about the purpose and procedure of the study, including data protection and anonymity assurances. No ethical approval was sought, as the nature of the study did not require formal review according to the applicable national and institutional guidelines.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used DeepL and ChatGPT in order to translate German expressions and improve writing clarity. After using these tools/services, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Table A.6
List of abbreviations used in the manuscript (alphabetical).

Abbreviation	Meaning	Category
A	Use/Apply (competency level; assessed)	DiKoLAN: level
ANOVA	Analysis of variance	Method
CFI	Comparative Fit Index	Fit index
CK	Content Knowledge	TPACK: area
COM	Communication and Collaboration	DiKoLAN: area
D	Describe (competency level; assessed)	DiKoLAN: level
DAQ	Data Acquisition	DiKoLAN: area
DAP	Data Processing	DiKoLAN: area
DiKoLAN	Digital Competencies for Teaching in Science Education (from German *Digitale Kompetenzen für das Lehramt in den Naturwissenschaften*)	Framework
DiKoLAN-SK	Academic self-concept regarding digitalization-related competencies for teaching science (construct)	Construct
DigCompEdu	European Framework for the Digital Competence of Educators	Framework/policy
DOC	Documentation	DiKoLAN: area
FDR	False discovery rate	Multiple testing
FIML	Full-information maximum likelihood	Estimator
IQR	Interquartile range	Descriptive
ISE	Information Search and Evaluation	DiKoLAN: area
MANOVA	Multivariate analysis of variance	Method
N	Name (competency level; shown for completeness, not assessed)	DiKoLAN: level
PCK	Pedagogical Content Knowledge	TPACK: area
PK	Pedagogical Knowledge	TPACK: area
PRE	Presentation	DiKoLAN: area
RMSEA	Root Mean Square Error of Approximation	Fit index
R^2	Explained variance (coefficient of determination)	Model parameter
SIM	Simulation and Modeling	DiKoLAN: area
SRMR	Standardized Root Mean Square Residual	Fit index
TCK	Technological Content Knowledge	TPACK: area
TK	Technological Knowledge	TPACK: area
TLI	Tucker–Lewis Index	Fit index
TPACK	Technological Pedagogical Content Knowledge	Framework
TPACK (facet)	Technological Pedagogical Content Knowledge (integrated knowledge facet)	TPACK: area
TPK	Technological Pedagogical Knowledge	TPACK: area
WLSMV	Weighted least squares means and variance adjusted estimation	Estimator
α	Cronbach's alpha (internal consistency)	Reliability
δ	Cliff's dominance statistic (effect size for pairwise comparisons)	Effect size
E_H^2	Eta-squared type measure for Kruskal–Wallis (association measure)	Effect size
ω_p^2	Partial omega squared (effect size; e.g., permutation MANOVA/`adonis2`)	Effect size
χ^2	Chi-square test statistic	Test statistic

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. List of abbreviations

See Table A.6.

Appendix B. Supplementary tables

See Tables B.7–B.12.

Appendix C. Validated final DiKoLAN-SK questionnaire (German original)

See Tables C.13–C.19. This appendix contains the validated final item set (instrument).

Table B.7
Academic self-concept versus self-efficacy: conceptual and measurement-related differences.

	Academic self-concept	Self-efficacy
Definition	Evaluative self-perception of competence in a domain [25,26]	Belief in capability to successfully perform specific actions in specific situations [19]
Structure	Relatively stable; hierarchical and multidimensional; strongly domain-specific [25]	More task-/context-specific; varies with demands, constraints, and prior mastery experiences [19]
Typical measurement focus	"How good am I in this domain?"/perceived competency level	"Can I succeed at this task under these conditions?"
Typical use in research	Describing self-perceptions linked to learning pathways and professional development	Predicting goal-directed action, persistence, and performance in concrete tasks

Table B.8
Software and package versions used for statistical analyses.

Software/package	Version	Citation
R	4.4.3	R Core Team [59]
lavaan	0.6–19	Rosseel et al. [60],Rosseel [61]
vegan	2.6–8	Oksanen et al. [67]
MicEco	0.9.19	Russel [68]
pairwiseAdonis	0.4.1	Arbizu [69]
dunn.test	1.3.6	Dinno [72]
rcompanion	2.4.36	Mangiafico [76]

Note. Stand-alone, formatted PDFs and matching LimeSurvey (.lss) files are provided in the online supplementary materials for direct use in data collection. In addition, the German questionnaire is provided in machine-readable formats (XLSX and CSV) to support reuse, replication, and automated processing. The present Appendix B documents the German wording for transparency and is not formatted for administration.

Appendix D. Validated final DiKoLAN-SK questionnaire (English translation)

This appendix contains the English translation of the validated final item set (instrument). The survey in this study was conducted using the German-language questionnaire. For the convenience of the reader, we have carefully translated the questionnaire into English. We followed a multi-stage process with the aim of making the translation as faithful to the original as possible, idiomatic, and easy to understand for an equivalent English-speaking target group, thus providing a basis for further studies (cognitive pretesting, piloting, etc.).

1. Five translations of the questionnaire were created:
   - Direct translation by one of the authors
   - Machine translation by DeepL Pro with review of alternative formulations
   - Machine translation with explanations by GPT-4.0
   - Machine translation with explanations by GPT-4o
   - Machine translation with explanations by GPT-4.5
2. Compilation of a translation manual for technical terms
3. Consolidation of the translations by one author
4. Review of the translation by a team of experts
5. Review of the translation by a bilingual expert

Note. Stand-alone, formatted PDFs and matching LimeSurvey (.lss) files are provided in the online supplementary materials for direct use in data collection. In addition, the English questionnaire is provided in machine-readable formats (XLSX and CSV) to support reuse, replication, and automated processing. The present Appendix C documents the English wording for transparency and is not formatted for administration.

Table B.9
List of the adaptations made to the introductory texts. Comparison of the original and the adaptation with reasoning/commentary.

Area	Sec.	Comp.	BP	Original	New	Comment
DOC	TA	87.8	3	Versionsverwaltungen **wie z. B. zur Versionierung von Textdateien sowie Apple Time Machine** zur Datenarchivierung	Versionsverwaltungen **zur Erfassung von Änderungen an Dokumenten oder Dateien und** zur Datenarchivierung	“Apple Time Machine” was frequently marked as unknown; revised based on the definition of “Versionsverwaltung [version control]” from Wikipedia.
DOC	OP	94.9	4	Nutzung einer Versionsverwaltung, um **mehrere Versionen einer Datei zu speichern**	Nutzung einer Versionsverwaltung, um **Änderungen an Dokumenten oder Dateien zu erfassen**	Revised based on the definition of “Versionsverwaltung [version control]” from Wikipedia. (see above).
DOC	SC	92.8	1	Nutzung digitaler Laborbücher	Nutzung digitaler Laborbücher **und -protokolle**	“Laborbücher [lab notebooks]” was frequently marked as unknown, so the term “Protokolle [lab report],” which is used in schools, was added.
DOC	SC	92.8	2	Speicherung von **Gensequenzen, Spektraldaten oder Datenblätter in Datenbanken**	Speicherung von **Datenblättern, Gensequenzen oder Spektraldaten**	Order changed: from familiar to unfamiliar. Removed “in Datenbanken [in databases]”.
COM	SC	87.5	1	**kollaborative** Laborbücher	**gemeinsame** Laborbücher	“kollaborative [collaborative]” was frequently marked as unknown and also has a different meaning in German (cooperation with the enemy), so it was replaced with “gemeinsame [joint]”.
COM	SC	87.5	2	**kollaborative** Projekte **wie SETI@Home und Stall Catchers**	**gemeinsame** Projekte**, in denen automatisiert die eigene Rechnerleistung mit anderen geteilt wird**	“kollaborative [collaborative]” was frequently marked as unknown and also has a different meaning in German (cooperation with the enemy), so it was replaced with “gemeinsame [joint]”; “SETI@Home” and “Stall Catchers” were frequently marked as unknown, so the point was changed to “joint projects in which one’s own computer power is automatically shared with others”.
COM	SC	87.5	3	**kollaborative** Dokumentbearbeitung bei Publikationen	**gemeinsame** Dokumentbearbeitung bei Publikationen	“kollaborative [collaborative]” was frequently marked as unknown and also has a different meaning in German (cooperation with the enemy), so it was replaced with “gemeinsame [joint]”.
ISE	SC	91.5		**Spektral- oder Gendatenbanken**	**Spektral- oder Gendatenbanken**	No alternative to “spectral or gene databases.”
DAQ	TA	90.2	1	welche Messwerte, wie z. B. Strahlung, **Vitalparameter** erfassen und digitalisieren.	welche Messwerte, wie z. B. Strahlung, **Messdaten wichtiger Körperfunktionen** erfassen und digitalisieren.	“Vitalparameter [Vital parameters]” often marked as unknown, therefore changed in description to “measurement data of important bodily functions”.
DAQ	TA	90.2	S	Die Messcharakteristika, wie z. B. Messbereich, Messgenauigkeit, Auflösung, **Abtastrate**, Einsatzbereiche, Limitierungen, müssen berücksichtigt und das Messsystem muss kalibriert und justiert werden.	Die Messcharakteristika, wie z. B. Messbereich, Messgenauigkeit, Auflösung, **Messhäufigkeit pro Zeiteinheit (Abtastrate)**, Einsatzbereiche, Limitierungen, müssen berücksichtigt und das Messsystem muss kalibriert und justiert werden.	“Abtastrate [sampling rate]” often unknown, therefore “measurement frequency per unit of time” added as description.
DAQ	OP	94.9	1	Nutzung computergestützter Messwerterfassung **(z. B. Leybold CASSY)**	Nutzung computergestützter Messwerterfassung	“Leybold CASSY” very often unknown, therefore removed.
DAQ	SC	94.1	3	pH-Wert-Erfassung **in einer Titration**	pH-Wert-Erfassung	“Titration” is often unknown, and pH measurements are also taken outside of titration, so it has been removed.
DAP	SC	85.7	3	**Colorimetrie (DNA-Arrays, Konzentrationsmessungen)**	**Konzentrationsberechnungen aus Farbmessungen (Kolorimetrie)**	Definition of colorimetry added
SIM	OP	93.8	1	die **Generierung** von Daten im Erkenntnisgewinnungsprozess, z.B. mit **Tabellenkalkulations- oder Simulationsprogrammen**.	die **Erzeugung** von Daten im Erkenntnisgewinnungsprozess, z. B. mit **Tabellenkalkulationsprogrammen oder Simulationen**.	“Generierung [generation]” often marked as unknown, therefore replaced with “creation”. “Tabellenkalkulations- oder Simulationsprogrammen [spreadsheet or simulation software]” often marked as unknown, therefore “Simulationsprogramme [simulation software]” specified as “simulations” and phrase replaced with “spreadsheet software or simulations”.
SIM	OP	93.3	2	die Veranschaulichung und Erkundung fachlicher Zusammenhänge mit **fertigen Simulationsprogrammen**.	die Veranschaulichung und Erkundung fachlicher Zusammenhänge mit **verfügbaren Simulationen**.	It is unclear what is meant by “fertige Simulationsprogramme [ready-to-use simulation software]”, so this has been replaced by “verfügbare Simulationen [available simulations]”. (Not programming, but finding and applying).
SIM	PA	93.8	2	**Usability**	**Benutzerfreundlichkeit**	“Usability” is often unknown, replaced by the German equivalent “Benutzerfreundlichkeit” (user-friendliness).

Note: Sec.: Section; *Comp.*: Comprehensibility in %; *BP*: Bullet point; *DOC*: Documentation; *COM*: Communication/Collaboration; *ISE*: Information Search and Evaluation; *DAQ*: Data Acquisition; *DAP*: Data Processing; *SIM*: Simulation and Modeling; *TA*: Technical approaches; *OP*: Opportunities; *SC*: Scientific contexts; *PA*: Pedagogical Aspects. Changes in bold indicate adapted wording based on expert feedback.

Table B.10
Results of Wilcoxon signed-rank tests to examine whether academic self-concept is more pronounced in Describe than in Use/Apply. Adjusted p-values (Benjamini–Hochberg procedure) [64]. Exploratory/descriptive item-level comparisons (difficulty ordering); not part of the instrument presentation.

Item	Describe					Use/Apply					Wilcoxon signed-rank test			
	n	Mdn	IQR	M	SD	n	Mdn	IQR	M	SD	V	p_{adj}	r	Hypothesis
DOC_TA	261	6.0	2.00	6.05	1.56	258	6.0	2.00	6.14	1.51	4607.5	0.84	0.01	reject
PRE_TA	264	7.0	2.00	6.83	1.24	265	7.0	2.00	6.77	1.23	2664.5	0.38	0.06	reject
COM_TA	268	6.0	1.25	6.22	1.52	268	7.0	2.00	6.16	1.62	3657.0	0.38	0.06	reject
ISE_TA	256	6.0	2.00	6.10	1.45	257	7.0	1.00	6.33	1.42	5236.5	1.00	0.18	reject
DAQ_TA	266	6.0	3.00	5.18	1.88	265	5.0	3.00	4.87	1.94	2707.5	<0.001	0.30	accept
DAP_TA	267	6.0	2.00	5.57	1.74	267	6.0	3.00	5.19	1.94	3200.0	<0.001	0.29	accept
SIM_TA	264	5.0	3.00	4.78	1.79	260	4.5	3.00	4.39	1.87	3134.0	<0.001	0.33	accept
DOC_OP	265	7.0	2.00	6.29	1.37	263	7.0	1.00	6.28	1.43	3870.0	0.61	0.01	reject
PRE_OP	265	7.0	2.00	6.89	1.18	264	7.0	2.00	6.79	1.23	2132.5	0.07	0.14	reject
COM_OP	267	7.0	1.00	6.41	1.42	264	7.0	1.00	6.27	1.50	2827.5	0.04	0.15	accept
ISE_OP	258	7.0	1.00	6.40	1.32	256	7.0	1.00	6.45	1.43	4048.5	0.84	0.02	reject
DAQ_OP	265	6.0	3.00	5.37	1.80	264	5.0	4.00	4.99	1.94	2763.0	<0.001	0.32	accept
DAP_OP	267	6.0	2.00	5.61	1.72	266	5.5	3.00	5.18	1.93	2622.0	<0.001	0.37	accept
SIM_OP	263	5.0	2.00	5.03	1.81	258	5.0	3.00	4.46	1.87	2615.0	<0.001	0.43	accept
PRE_SC	264	6.0	1.00	6.33	1.26	266	6.0	2.00	6.12	1.50	4736.5	0.04	0.13	accept
ISE_SC	256	6.0	2.00	5.75	1.44	249	6.0	2.00	5.61	1.63	3789.5	0.04	0.13	accept
DAQ_SC	264	6.0	3.00	5.24	1.89	261	5.0	4.00	4.87	2.07	3314.0	<0.001	0.28	accept

Table B.11
Results of Wilcoxon signed rank tests to examine whether academic self-concept is more pronounced in Planning teaching scenarios than in Conducting teaching scenarios. Adjusted p-values (Benjamini–Hochberg procedure) [64]. Exploratory/descriptive item-level comparisons; not part of the instrument presentation.

Item	Planning					Conducting					Wilcoxon signed-rank test			
	n	Mdn	IQR	M	SD	n	Mdn	IQR	M	SD	V	p_{adj}	r	Hypothesis
DOC_L	264	6.0	2.00	5.71	1.70	261	6.0	2.00	5.71	1.73	3185.0	0.3900	0.04	reject
PRE_L	266	7.0	2.00	6.51	1.41	263	7.0	1.00	6.35	1.47	1087.0	<0.001	0.22	accept
COM_L	266	6.0	2.00	5.79	1.68	262	6.0	2.00	5.65	1.73	798.0	<0.001	0.25	accept
ISE_L	258	6.0	2.00	5.77	1.61	252	6.0	2.00	5.64	1.65	762.0	0.0028	0.20	accept
DAQ_L	267	5.0	3.00	5.06	1.95	263	5.0	3.00	5.02	2.02	2243.0	0.2000	0.09	reject
DAP_L	267	5.0	3.00	4.98	1.94	264	5.0	3.00	4.80	1.94	1111.5	<0.001	0.25	accept
SIM_L	260	5.0	3.00	4.64	1.97	255	5.0	3.00	4.53	2.01	1363.0	0.0028	0.21	accept

Table B.12
Mean values and standard deviations (M(SD)) of the scores in the seven competency areas across groups used in known-groups comparisons. Descriptive statistics for known-groups sensitivity analyses; not part of the instrument presentation.

Grouping variable	Group	DOC	PRE	COM	ISE	DAQ	DAP	SIM
Science subjects	Zero	5.67(1.28)	6.34(1.05)	5.78(1.51)	5.90(1.11)	3.75(1.54)	4.47(1.55)	4.08(1.70)
	One	5.99(1.19)	6.54(0.95)	5.98(1.20)	6.00(1.11)	5.46(1.46)	5.37(1.50)	5.01(1.44)
	Two	6.13(1.25)	6.12(1.43)	5.86(1.16)	6.00(1.46)	5.75(1.32)	5.57(1.71)	5.16(1.70)
Training phase	Bachelor	5.66(1.28)	6.17(1.23)	5.85(1.21)	5.70(1.40)	5.03(1.58)	4.95(1.60)	4.82(1.54)
	Master	5.88(1.23)	6.52(0.94)	5.95(1.25)	6.05(1.03)	4.82(1.78)	5.02(1.59)	4.67(1.64)
Target school level	Primary	5.81(1.14)	6.36(0.94)	5.72(1.56)	5.87(1.08)	4.12(1.68)	4.63(1.55)	4.02(1.82)
	Lower secondary	5.92(1.32)	6.34(1.06)	5.81(1.44)	5.76(1.36)	5.19(1.74)	5.23(1.68)	4.68(1.55)
	Upper secondary	5.94(1.21)	6.53(1.02)	6.00(1.11)	6.06(1.06)	5.39(1.44)	5.33(1.49)	5.06(1.39)

Note: DOC: Documentation; *PRE*: Presentation; *COM*: Communication/Collaboration; *ISE*: Information Search and Evaluation; *DAQ*: Data Acquisition; *DAP*: Data Processing; *SIM*: Simulation and Modeling. Response scale: 1 — *I cannot do it at all* to 8 — *I can do it perfectly*.

Appendix E. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.caeo.2026.100338.

Data availability

The validated DiKoLAN-SK questionnaire and accompanying materials are available in the online Supplementary Materials as ready-to-administer downloads:

1. formatted, editable DOCX files (German original; English translation) matching the validated item set;
2. formatted, print-ready PDF files (German original; English translation) matching the validated item set;
3. LimeSurvey import files (.lss) with the eight-point forced-choice response format preconfigured (exported from LimeSurvey v5.6.68+ 240625);
4. machine-readable instrument files in XLSX and CSV format (German original; English translation), including item codes, competency areas, item texts, and the corresponding item-stem/context blocks to support replication and reuse; and
5. a multi-page PDF *Visual Scoring Guide* describing scoring, implementation, and interpretation procedures.

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Table C.13
Item stem and item texts in the competency area of documentation (German original).

Kompetenzbereich Dokumentation

Mit Kompetenzen aus dem **Kompetenzbereich Dokumentation** können Sie digitale Werkzeuge fachgemäß nutzen, um Daten sowie Informationen systematisch abzulegen und dauerhaft zu speichern. Dazu gehört auch, verschiedene Medien zu kombinieren und zu speichern, Informationen strukturiert zu sichern und zu archivieren sowie Abläufe und Sinnzusammenhänge (also z. B. Wechselwirkungen in Fließdiagrammen oder Concept-Maps) darzustellen.

I. **Technische Ansätze** zur digitalen Dokumentation sind z. B.:
- Text-, Bild- und/oder Tonverarbeitungsprogramme wie Word, OneNote oder PowerPoint zur Dokumentation
- Datenspeicherungssysteme wie z. B. Festplatten oder Cloudspeicher zur dauerhaften Datenspeicherung
- Versionsverwaltungen zur Erfassung von Änderungen an Dokumenten oder Dateien und zur Datenarchivierung

II. **Möglichkeiten** der digitalen Dokumentation sind z. B.:
- digitale Protokollierung
- Durchführung von Backups zur Datensicherung
- Datenarchivierung für eine langfristige sichere Datenspeicherung
- Nutzung einer Versionsverwaltung, um Änderungen an Dokumenten oder Dateien zu erfassen

III. In den **Fachwissenschaften** umfasst digitale Dokumentation z. B.:
- Nutzung digitaler Laborbücher und -protokolle
- Speicherung von Datenblättern, Gensequenzen oder Spektraldaten

IV. **Pädagogische Aspekte**, die beim unterrichtlichen Einsatz digitaler Dokumentation und -medien berücksichtigt werden müssen, sind z. B.:
- Zugang zu den Speichersystemen herstellen (z. B. zur Schulcloud)
- Zeitaufwand und Hardwarebedarf
- Zugriffsbeschränkungen
- passende Organisationsform
- persönliche und soziale Konsequenzen

Schätzen Sie Ihre fachbezogenen digitalen Kompetenzen im Bereich Dokumentation ein!
Kreuzen Sie an, inwieweit Sie den folgenden Aussagen bzw. Kompetenzbeschreibungen zustimmen.

Item code	Item text (rating scale: 1 — *Kann ich ganz und gar nicht.* to 8 — *Kann ich voll und ganz.*).
DO_TAB	Ich kann **technische Ansätze** zur digitalen Dokumentation beschreiben.
DO_MOB	Ich kann **Möglichkeiten** der digitalen Dokumentation beschreiben.
DO_TAA	Ich kann **technische Ansätze** zur digitalen Dokumentation anwenden.
DO_MOA	Ich kann **Möglichkeiten** der digitalen Dokumentation anwenden.
DO_FWB	Ich kann in den **Fachwissenschaften** genutzte digitale Dokumentation beschreiben.
DO_PAB	Ich kann **pädagogische Aspekte** bzgl. Vor- und Nachteilen für den Einsatz digitaler Dokumentation im Unterricht beschreiben.
DO_EUB	Ich kann das **Ziel des Einsatzes** von digitaler Dokumentation im Unterricht beschreiben.
DO_FVB	Ich kann **fachdidaktische Voraussetzungen** für den Einsatz digitaler Dokumentation im Unterricht beschreiben.
DO_MAB	Ich kann mögliche Auswirkungen des Einsatzes digitaler Dokumentation auf **Unterrichtsverfahren** beschreiben.
DO_UNP	Ich kann **Unterricht** planen, in dem Techniken zur digitalen Dokumentation unter der Berücksichtigung geeigneter Sozial- und Organisationsformen integriert sind.
DO_UND	Ich kann **Unterricht** mit Anwendung von Techniken zur digitalen Dokumentation unter der Berücksichtigung geeigneter Sozial- und Organisationsformen durchführen.

Table C.14
Item stem and item texts in the competency area of presentation (German original).

Kompetenzbereich Präsentation

Mit Kompetenzen aus dem **Kompetenzbereich Präsentation** können Sie digitale Medien für den Erkenntnis- und Kommunikationsprozess einsetzen sowie Grenzen und Potenziale unterschiedlicher digitaler Präsentationsmedien und -techniken bei der Unterrichtsplanung einschätzen.

I. **Technische Ansätze** zur digitalen Präsentation mittels digitaler Präsentationssysteme sind z. B.:
- Wiedergabe mittels Beamer, interaktivem Whiteboard und auf einem einzelnen oder mehreren Endgeräten
- Aufnahme mittels Dokumentenkamera, Videokamera, Smartphone, Tablet oder Mikroskopkamera
- Kopplung mehrerer Geräte (z. B. Beamer und Laptop/Tablet)

II. **Möglichkeiten** der digitalen Präsentation sind z. B. Darstellung von…
- Inhalten für die ganze Klasse, individuell für mehrere Gruppen oder einzelne Personen
- Inhalten unterschiedlicher Größenordnungen (z. B. mikroskopische Aufnahmen, Aufnahmen aus der Vogelperspektive)
- Prozessen auf unterschiedlichen Zeitskalen (z. B. Zeitlupe, Zeitraffer)

III. In den **Fachwissenschaften** umfassen digitale Präsentationsformen und -medien z. B.:
- das Anfertigen von Diagrammen
- Hochgeschwindigkeitsaufnahmen von Kollisionen
- Zeitrafferaufnahmen von Pflanzenwachstum oder Landschaftsentwicklungen
- dreidimensionale Darstellungen von Molekülschwingungen

IV. **Pädagogische Aspekte**, die beim unterrichtlichen Einsatz digitaler Präsentationsformen und -medien berücksichtigt werden müssen, sind z. B.:
- Verfügbarkeit der Systeme
- Zeitaufwand und Hardwarebedarf
- passende Organisationsform
- persönliche und soziale Konsequenzen

Schätzen Sie Ihre fachbezogenen digitalen Kompetenzen im Bereich Präsentation ein!
Kreuzen Sie an, inwieweit Sie den folgenden Aussagen bzw. Kompetenzbeschreibungen zustimmen.

Item code	Item text (rating scale: 1 — *Kann ich ganz und gar nicht.* to 8 — *Kann ich voll und ganz.*).
PR_TAB	Ich kann **technische Ansätze** zur digitalen Präsentation beschreiben.
PR_MOB	Ich kann **Möglichkeiten** der digitalen Präsentation beschreiben.
PR_TAA	Ich kann **technische Ansätze** zur digitalen Präsentation anwenden.
PR_MOA	Ich kann **Möglichkeiten** der digitalen Präsentation anwenden.
PR_FWB	Ich kann in den **Fachwissenschaften** genutzte digitale Präsentationsformen und -medien beschreiben.
PR_FWA	Ich kann Präsentationen unter Verwendung digitaler Präsentationsmedien in Kontexten der **Fachwissenschaften** erstellen und vorführen.
PR_PAB	Ich kann **pädagogische Aspekte** bzgl. Vor- und Nachteilen für den Einsatz digitaler Präsentationen im Unterricht beschreiben.
PR_EUB	Ich kann das **Ziel des Einsatzes** von digitalen Präsentationstechniken im Unterricht beschreiben.
PR_FVB	Ich kann **fachdidaktische Voraussetzungen** des Einsatz digitaler Präsentationstechniken im Unterricht beschreiben.
PR_MAB	Ich kann mögliche Auswirkungen des Einsatzes digitaler Präsentationstechniken auf **Unterrichtsverfahren** beschreiben.
PR_UNP	Ich kann **Unterricht** planen, in dem digitale Präsentationsmedien und -formen unter der Berücksichtigung geeigneter Sozial- und Organisationsformen integriert sind.
PR_UND	Ich kann **Unterricht** durchführen, in dem digitale Präsentationsmedien und -formen unter der Berücksichtigung geeigneter Sozial- und Organisationsformen integriert sind.

Table C.15
Item stem and item texts in the competency area of communication/collaboration (German original).

Kompetenzbereich Kommunikation und Kollaboration

Mit Kompetenzen aus dem **Kompetenzbereich Kommunikation und Kollaboration** können Sie mit digitalen Werkzeugen synchrones oder asynchrones Arbeiten von Einzelpersonen oder Gruppen auf ein gemeinsames Ziel hin planen und mit Lernenden durchführen. Dazu können Sie gemeinsame Dateien oder Produkte erstellen und bearbeiten, gemeinsame Datenpools anlegen und bearbeiten sowie User-Berechtigungen systematisch verwalten.

I. **Technische Ansätze** zur digitalen Kommunikation und Kollaboration sind z. B.:
- Software für gemeinsame Text- und Datenverarbeitung (z. B. Office 365, Google Docs, Etherpad)
- gemeinsam nutzbare Cloud-Speicher (z. B. Dropbox, OneDrive, Schulcloud)

II. **Möglichkeiten** zur digitalen Kommunikation und Kollaboration sind z. B.:
- Bereitstellung von Informationen, Lernmaterial und Arbeitsaufträgen
- gemeinsame, synchrone oder asynchrone Dokumentenbearbeitung
- gemeinsames Verwenden und Bearbeiten von Daten
- gemeinsamer Austausch über Lernplattformen

III. In den **Fachwissenschaften** umfassen die digitale Kommunikation und Kollaboration z. B.:
- gemeinsame Laborbücher
- gemeinsame Projekte, in denen automatisiert die eigene Rechnerleistung mit anderen geteilt wird
- gemeinsame Dokumentbearbeitung bei Publikationen
- Kommunikation mit (inter)nationalen Kolleg:innen
- Wissensorganisation und Strukturierung z. B. über Wikis

IV. **Pädagogische Aspekte**, die beim unterrichtlichen Einsatz digitaler Kommunikation und Kollaboration berücksichtigt werden müssen, sind z. B.:
- Zeitaufwand
- Soft- und Hardwarebedarf
- Organisationsform/-en der Zusammenarbeit
- Datensicherheit und Datenschutz
- persönliche und soziale Konsequenzen

Schätzen Sie Ihre fachbezogenen digitalen Kompetenzen im Bereich Kommunikation und Kollaboration ein!
Kreuzen Sie an, inwieweit Sie den folgenden Aussagen bzw. Kompetenzbeschreibungen zustimmen.

Item code	Item text (rating scale: 1 — *Kann ich ganz und gar nicht.* to 8 — *Kann ich voll und ganz.*).
KK_TAB	Ich kann **technische Ansätze** zur digitalen Kommunikation/Kollaboration beschreiben.
KK_MOB	Ich kann **Möglichkeiten** der digitalen Kommunikation/Kollaboration beschreiben.
KK_TAA	Ich kann **technische Ansätze** zur digitalen Kommunikation/Kollaboration anwenden.
KK_MOA	Ich kann **Möglichkeiten** der digitalen Kommunikation/Kollaboration anwenden.
KK_FWB	Ich kann in den **Fachwissenschaften** genutzte digitale Kommunikation und Kollaboration beschreiben.
KK_PAB	Ich kann **pädagogische Aspekte** bzgl. Vor- und Nachteilen für den Einsatz digitaler Kommunikation und Kollaboration im Unterricht beschreiben.
KK_EUB	Ich kann das **Ziel des Einsatzes** von digitaler Kommunikation und Kollaboration im Unterricht beschreiben.
KK_FVB	Ich kann **fachdidaktische Voraussetzungen** für den Einsatz digitaler Kollaboration und Kommunikation im Unterricht beschreiben.
KK_MAB	Ich kann mögliche Auswirkungen des Einsatzes digitaler Kollaboration und Kommunikation auf **Unterrichtsverfahren** beschreiben.
KK_UNP	Ich kann **Unterricht** planen, in dem digitale Kollaboration und Kommunikation unter der Berücksichtigung geeigneter Sozial- und Organisationsformen integriert ist.
KK_UND	Ich kann **Unterricht** durchführen, in dem digitale Kollaboration und Kommunikation unter der Berücksichtigung geeigneter Sozial- und Organisationsformen integriert ist.

Table C.16
Item stem and item texts in the competency area of information search and evaluation (German original).

Kompetenzbereich Recherche und Bewertung

Mit Kompetenzen aus dem **Kompetenzbereich Recherche und Bewertung** können Sie mit digitalen Werkzeugen Informationen zu vorgegebenen Themenbereichen oder zur Lösung von Fragestellungen beschaffen, diese strukturieren und bewerten. Dazu definieren Sie Such- bzw. Rechercheziele, binden verschiedene Informationsquellen ein und bewerten nach digitalisierungsbezogenen Qualitätskriterien.

I. **Technische Ansätze** beinhalten die Ausübung von Recherchestrategien, wie z. B.:
- die Auswahl passender Suchmaschinen
- die Kombination von Suchbegriffen
- die Suchfunktionen von u. a. Bibliotheksseiten und Datenbanken berücksichtigen

und dabei sind digitalisierungsbezogene **Qualitätskriterien** besonders relevant, wie z. B.:
- der Einfluss von Rankingalgorithmen auf Suchergebnisse
- Standorte von Servern
- unklare Autorenschaften und Erstellungszeitpunkte

II. **Möglichkeiten** zur digitalen Recherche und Bewertung sind z. B.:
- Beschaffung von Informationen aus digitalen Informationsquellen (Nachschlagewerke, Zeitschriften, Datenbanken)
- Strukturierung von Informationen mit digitalen Werkzeugen
- Bewertung von Informationen mit (digitalisierungsbezogenen) Qualitätskriterien

III. In den **Fachwissenschaften** gibt es fachspezifische digitale Informationsquellen, z. B.:
- Spektral- oder Gendatenbanken
- Fachzeitschriften
- Informationsportale

die nach digitalisierungsbezogenen Qualitätskriterien in den Fachwissenschaften beurteilt werden können.

IV. **Pädagogische Aspekte**, die beim unterrichtlichen Einsatz digitaler Recherche und Bewertung von digitalen Informationsquellen berücksichtigt werden müssen, sind z. B.:
- Zugang zu digitalen Informationsquellen
- Zeitaufwand und Hardwarebedarf
- Zugriffsbeschränkungen
- passende Organisationsform
- persönliche und soziale Konsequenzen

Schätzen Sie Ihre fachbezogenen digitalen Kompetenzen im Bereich Recherche und Bewertung ein!
Kreuzen Sie an, inwieweit Sie den folgenden Aussagen bzw. Kompetenzbeschreibungen zustimmen.

Item code	Item text (rating scale: 1 — *Kann ich ganz und gar nicht.* to 8 — *Kann ich voll und ganz.*).
RB_TAB	Ich kann **technische Ansätze** zur digitalen Recherche und Bewertung beschreiben.
RB_MOB	Ich kann **Möglichkeiten** der digitalen Recherche und Bewertung beschreiben.
RB_TAA	Ich kann **technische Ansätze** zur digitalen Recherche und Bewertung anwenden.
RB_MOA	Ich kann **Möglichkeiten** der digitalen Recherche und Bewertung anwenden.
RB_FWB	Ich kann in den **Fachwissenschaften** genutzte digitale Recherche und Bewertung beschreiben.
RB_FWA	Ich kann eine Recherche gemäßQualitätskriterien aus den **Fachwissenschaften** durchführen.
RB_PAB	Ich kann **pädagogische Aspekte** bzgl. Vor- und Nachteilen für den Einsatz digitaler Recherche und Bewertung im Unterricht beschreiben.
RB_EUB	Ich kann das **Ziel des Einsatzes** von digitaler Recherche und Bewertung im Unterricht beschreiben.
RB_FVB	Ich kann **fachdidaktische Voraussetzungen** des Einsatzes von digitaler Recherche und Bewertung im Unterricht beschreiben.
RB_MAB	Ich kann mögliche Auswirkungen des Einsatzes digitaler Recherche und Bewertung auf **Unterrichtsverfahren** beschreiben.
RB_UNP	Ich kann **Unterricht** planen, in dem digitale Recherche und Bewertung unter der Berücksichtigung geeigneter Sozial- und Organisationsformen integriert ist.
RB_UND	Ich kann **Unterricht** durchführen, in dem digitale Recherche und Bewertung unter der Berücksichtigung geeigneter Sozial- und Organisationsformen integriert ist.

Table C.17
Item stem and item texts in the competency area of data acquisition (German original).

Kompetenzbereich Messwert- und Datenerfassung

Mit Kompetenzen aus dem **Kompetenzbereich Messwert- und Datenerfassung** können Sie mit digitalen Werkzeugen Daten erheben, indem Sie (Mess-)Daten eingeben, analoge Daten digitalisieren, Bilder sowie Filme anfertigen, Sonden, Sensoren und Programme/Apps einsetzen und Messwerte aus Dokumentationsmedien, wie Bildern oder Videos, gewinnen.

I. **Technische Ansätze** umfassen digitale Messsysteme…
- welche Messwerte, wie z. B. Strahlung, Messdaten wichtiger Körperfunktionen erfassen und digitalisieren.

Die Messcharakteristika, wie z. B. Messbereich, Messgenauigkeit, Auflösung, Messhäufigkeit pro Zeiteinheit (Abtastrate), Einsatzbereiche, Limitierungen, müssen berücksichtigt und das Messsystem muss kalibriert und justiert werden.

II. **Möglichkeiten** zur digitalen Erfassung von Messwerten und Daten sind z. B.:
- Nutzung computergestützter Messwerterfassung
- Nutzung integrierter Messsensoren in mobilen Endgeräten (z. B. Beschleunigungssensoren)
- Nutzung externer Messsensoren mit mobilen Endgeräten (z. B. Wärmebildkameras, pH-Sensoren, Fitness-Tracker)
- Videoanalyse von Bewegungen

III. In den **Fachwissenschaften** umfasst digitale Messwert- und Datenerfassung z. B.:
- Videoanalyse von Stoßversuchen
- Aufnahme der Herzfrequenz
- pH-Wert-Erfassung

III. **Pädagogische Aspekte**, die beim unterrichtlichen Einsatz digitaler Messsysteme berücksichtigt werden müssen, sind z. B.:
- Verfügbarkeit von Messsystemen
- Zeitaufwand und Hardwarebedarf
- Möglichkeiten der Messwertdarstellung
- passende Organisationsform
- persönliche und soziale Konsequenzen

Schätzen Sie Ihre fachbezogenen digitalen Kompetenzen im Bereich Messwert- und Datenerfassung ein!
Kreuzen Sie an, inwieweit Sie den folgenden Aussagen bzw. Kompetenzbeschreibungen zustimmen.

Item code	Item text (rating scale: 1 — *Kann ich ganz und gar nicht.* to 8 — *Kann ich voll und ganz.*).
MD_TAB	Ich kann **technische Ansätze** zur digitalen Messwert- und Datenerfassung beschreiben.
MD_MOB	Ich kann **Möglichkeiten** der digitalen Messwert- und Datenerfassung beschreiben.
MD_TAA	Ich kann **technische Ansätze** zur digitalen Messwert- und Datenerfassung anwenden.
MD_MOA	Ich kann **Möglichkeiten** der digitalen Messwert- und Datenerfassung anwenden.
MD_FWB	Ich kann in den **Fachwissenschaften** genutzte digitale Messwert- und Datenerfassung beschreiben.
MD_FWA	Ich kann Messwerte für Fragestellungen der **Fachwissenschaften** digital erfassen.
MD_PAB	Ich kann **pädagogische Aspekte** bzgl. Vor- und Nachteilen für den Einsatz digitaler Messwert- und Datenerfassung im Unterricht beschreiben.
MD_EUB	Ich kann das **Ziel des Einsatzes** von digitaler Messwert- und Datenerfassung im Unterricht beschreiben.
MD_FVB	Ich kann **fachdidaktische Voraussetzungen** für den Einsatz digitaler Messwert- und Datenerfassung im Unterricht beschreiben.
MD_MAB	Ich kann mögliche Auswirkungen des Einsatzes digitaler Messwert- und Datenerfassung auf **Unterrichtsverfahren** beschreiben.
MD_UNP	Ich kann **Unterricht** planen, in dem digitale Messwerterfassung unter der Berücksichtigung geeigneter Sozial- und Organisationsformen integriert ist.
MD_UND	Ich kann **Unterricht** durchführen, in dem digitale Messwerterfassung unter der Berücksichtigung geeigneter Sozial- und Organisationsformen integriert ist.

Table C.18
Item stem and item texts in the competency area of data processing (German original).

Kompetenzbereich Datenverarbeitung

Mit Kompetenzen aus dem **Kompetenzbereich Datenverarbeitung** können Sie Daten mit digitalen Werkzeugen strukturieren, weiterverarbeiten und analysieren. Sie können damit Daten filtern, neue Größen berechnen, Daten aufbereiten, statistische Analysen durchführen und Datensätze zusammenführen.

I. **Technische Ansätze** zur digitalen Datenverarbeitung sind z. B.:
- Tabellenkalkulationsprogramme (z. B. Excel)
- Nutzung von Datenbanken (z. B. zur Datenfilterung und -berechnung)
- Statistikprogramme zur Datenanalyse
- Bild- und Videobearbeitungsprogramme (z. B. Photoshop)
- Software zur Konvertierung von Datenformaten

II. **Möglichkeiten** der digitalen Datenverarbeitung sind z. B.:
- Konvertierung von Daten und Datenformaten
- Export und Import von digitalen Daten verschiedener Datentypen und Kodierungen
- Schutz und Anonymisierung von personenbezogenen Daten
- Aufbereitung von Daten zur Berechnung neuer Größen
- Datenanalyse

III. In den **Fachwissenschaften** umfasst digitale Datenverarbeitung z. B.:
- Verarbeitung großer Datensätze (Big-Data-Analysen)
- Bestimmung und Extraktion von Kurvenmaxima (z. B. Schallpegel, Beschleunigungsmessungen)
- Konzentrationsberechnungen aus Farbmessungen (Kolorimetrie)
- Berechnung von Messunsicherheiten (Standardfehler, Streuung, usw.)
- Konzentrationsberechnungen aus Stoffmengen- und Volumenangaben

IV. **Pädagogische Aspekte**, die beim unterrichtlichen Einsatz digitaler Datenverarbeitung berücksichtigt werden müssen, sind z. B.:
- Zeitaufwand
- Soft- und Hardwarebedarf
- Datensicherheit und Datenschutz
- passende Organisationsform
- persönliche und soziale Konsequenzen

Schätzen Sie Ihre fachbezogenen digitalen Kompetenzen im Bereich Datenverarbeitung ein!
Kreuzen Sie an, inwieweit Sie den folgenden Aussagen bzw. Kompetenzbeschreibungen zustimmen.

Item code	Item text (rating scale: 1 — *Kann ich ganz und gar nicht.* to 8 — *Kann ich voll und ganz.*).
DV_TAB	Ich kann **technische Ansätze** zur digitalen Datenverarbeitung beschreiben.
DV_MOB	Ich kann **Möglichkeiten** der digitalen Datenverarbeitung beschreiben.
DV_TAA	Ich kann **technische Ansätze** zur digitalen Datenverarbeitung anwenden.
DV_MOA	Ich kann **Möglichkeiten** der digitalen Datenverarbeitung anwenden.
DV_FWB	Ich kann in den **Fachwissenschaften** genutzte digitale Datenverarbeitung beschreiben.
DV_PAB	Ich kann **pädagogische Aspekte** bzgl. Vor- und Nachteilen für den Einsatz digitaler Datenverarbeitung im Unterricht beschreiben.
DV_EUB	Ich kann das **Ziel des Einsatzes** von digitaler Datenverarbeitung im Unterricht beschreiben.
DV_FVB	Ich kann **fachdidaktische Voraussetzungen** der digitalen Datenverarbeitung im Unterricht beschreiben.
DV_MAB	Ich kann die Auswirkungen des Einsatzes von digitaler Datenverarbeitung auf **Unterrichtsverfahren** beschreiben.
DV_UNP	Ich kann **Unterricht** planen, in dem digitale Datenverarbeitung unter der Berücksichtigung geeigneter Sozial- und Organisationsformen integriert ist.
DV_UND	Ich kann **Unterricht** durchführen, in dem digitale Datenverarbeitung unter der Berücksichtigung geeigneter Sozial- und Organisationsformen integriert ist.

Table C.19
Item stem and item texts in the competency area of simulation and modeling (German original).

Kompetenzbereich Simulation und Modellierung

Mit Kompetenzen aus dem **Kompetenzbereich Simulation und Modellierung** können Sie computergestützte Modellierungen erstellen sowie bestehende digitale Simulationen zielgerecht für den Erkenntnis- und Kommunikationsprozess einsetzen. Zudem können Sie Grenzen und Potenziale von Modellen und Simulationen im Erkenntnisgewinnungsprozess einschätzen.

I. **Technische Ansätze** zur digitalen Simulation und Modellierung sind z. B. Anwendungen, deren Funktionsumfang folgendes beinhalten kann:
- Mathematisierung und Modellbeschreibung mit Variablen
- Festlegung von Ausgabemöglichkeiten z. B. als Diagramme oder Datensätze

II. **Möglichkeiten** der digitalen Simulation und Modellierung sind z. B.:
- die Erzeugung von Daten im Erkenntnisgewinnungsprozess, z. B. mit Tabellenkalkulationsprogrammen oder Simulationen
- der Abgleich simulierter Daten mit experimentell gewonnen Daten, z. B. mit Tabellenkalkulationsprogrammen
- die Veranschaulichung und Erkundung fachlicher Zusammenhänge mit verfügbaren Simulationen

III. In den **Fachwissenschaften** umfassen digitale Simulation und Modellierung z. B.:
- Vorhersage von Entwicklungen (z. B. Klimamodelle, Wettervorhersage, Impfstoffentwicklung)
- Abgleich simulierter Daten mit experimentell gewonnenen Daten (z. B. Crashtests)
- Veranschaulichung und Erkenntnisgewinnung

IV. **Pädagogische Aspekte**, die beim unterrichtlichen Einsatz von Simulations- und Modellierungsanwendungen berücksichtigt werden müssen, sind z. B.:
- Passung an die Zielgruppe
- Benutzerfreundlichkeit
- Attraktivität der Benutzeroberfläche
- klare Beschreibung und Zielsetzung
- passende Organisationsform
- persönliche und soziale Konsequenzen

Schätzen Sie Ihre fachbezogenen digitalen Kompetenzen im Bereich Simulation und Modellierung ein!
Kreuzen Sie an, inwieweit Sie den folgenden Aussagen bzw. Kompetenzbeschreibungen zustimmen.

Item code	Item text (rating scale: 1 — *Kann ich ganz und gar nicht.* to 8 — *Kann ich voll und ganz.*).
SM_TAB	Ich kann **technische Ansätze** zur digitalen Simulation und Modellierung beschreiben.
SM_MOB	Ich kann **Möglichkeiten** der digitalen Simulation und Modellierung beschreiben.
SM_TAA	Ich kann **technische Ansätze** zur digitalen Simulation und Modellierung anwenden.
SM_MOA	Ich kann **Möglichkeiten** der digitalen Simulation und Modellierung anwenden.
SM_FWB	Ich kann in den **Fachwissenschaften** genutzte digitale Simulation und Modellierung beschreiben.
SM_PAB	Ich kann **pädagogische Aspekte** bzgl. Vor- und Nachteilen für den Einsatz digitaler Simulation und Modellierung im Unterricht beschreiben.
SM_EUB	Ich kann das **Ziel des Einsatzes** von digitalen Simulationen und Modellierung im Unterricht beschreiben.
SM_FVB	Ich kann **fachdidaktische Voraussetzungen** des Einsatzes von digitalen Simulationen und Modellierung im Unterricht beschreiben.
SM_MAB	Ich kann die Auswirkungen des Einsatzes digitaler Simulation und Modellierung auf **Unterrichtsverfahren** beschreiben.
SM_UNP	Ich kann **Unterricht** planen, in dem digitale Simulationen und/oder Modellierungen unter der Berücksichtigung geeigneter Sozial- und Organisationsformen integriert sind.
SM_UND	Ich kann **Unterricht** durchführen, in dem digitale Simulationen und/oder Modellierungen unter der Berücksichtigung geeigneter Sozial- und Organisationsformen integriert sind.

Table D.20
Item stem and item texts in the competency area of documentation (English translation).

Competency area *Documentation*

With competencies from the **competency area of documentation**, you are able to use digital tools professionally to systematically organize and permanently store data and information. This also includes combining and storing various types of media, saving and archiving information in a structured way, and presenting processes and relationships (e.g. interactions in flowcharts or concept maps).

I. **Technical approaches** to digital documentation include, for example:
- Text, image and/or audio processing tools such as Word, OneNote or PowerPoint for documentation
- Data storage systems such as hard drives or cloud storage for long-term data storage
- Version control systems for tracking changes to documents or files and for data archiving

II. **Opportunities** related to digital documentation include, for example:
- Digital logging
- Performing backups for data security
- Archiving data for long-term preservation
- Use of version control to record changes to documents or files

III. In **scientific disciplines**, digital documentation includes, for example:
- Use of digital lab notebooks and protocols
- Storage of data sheets, gene sequences, or spectral data

IV. **Pedagogical aspects** to consider when using digital documentation and media in the classroom are, for example:
- Ensuring access to storage systems (e.g. school cloud)
- Time requirements and hardware needs
- Access restrictions
- Suitable social organization of the classroom
- Personal and social consequences

Assess your subject-related digital competencies in the area of documentation!
Please indicate to what extent you agree with the following statements or competency descriptions.

Item code	Item text (rating scale: 1 — *I cannot do this at all.* to 8 — *I can do this perfectly.*).
DOC_DTA	I can describe **technical approaches** to digital documentation.
DOC_DOP	I can describe **opportunities** related to digital documentation.
DOC_ATA	I can apply **technical approaches** to digital documentation.
DOC_AOP	I can utilize **opportunities** related to digital documentation.
DOC_DSD	I can describe digital documentation used in **scientific disciplines**.
DOC_DPA	I can describe **pedagogical aspects** regarding the advantages and disadvantages of using digital documentation in the classroom.
DOC_DPU	I can describe the **purpose of using** digital documentation in the classroom.
DOC_DSR	I can describe **subject-specific didactic requirements** for the use of digital documentation in the classroom.
DOC_DTM	I can describe possible effects of the use of digital documentation on **teaching methods**.
DOC_PLL	I can plan **lessons** in which digital documentation techniques are integrated, taking into account appropriate modes of (social) interaction and social organization of the classroom.
DOC_COL	I can conduct **lessons** using digital documentation techniques, taking into account appropriate modes of (social) interaction and social organization of the classroom.

Table D.21
Item stem and item texts in the competency area of presentation (English translation).

Competency area *Presentation*

With competencies from the **competency area of presentation**, you are able to use digital media for the scientific inquiry and communication process, and to assess the limitations and potential of different digital presentation media and techniques in planning lessons.

I. **Technical approaches** to digital presentation include, for example:
- Playback via projector, interactive whiteboard and on a single or multiple end devices
- Recording using document cameras, video cameras, smartphones, tablets or microscope cameras
- Pairing multiple devices (e.g. projector and laptop or tablet)

II. **Opportunities** related to digital presentation include, for example, the display of …
- Content to the whole class, individually to several groups, or to individual learners
- Content at different scales (e.g. microscopic images, aerial images)
- Processes on various time scales (e.g. slow motion, time lapse)

III. In **scientific disciplines**, digital presentation formats and media include, for example:
- Creation of diagrams
- High-speed recordings of collisions
- Time-lapse recordings of plant growth or landscape development
- Three-dimensional representations of molecular vibrations

IV. **Pedagogical aspects** to consider when using digital forms of presentation and presentation media in the classroom are, for example
- Availability of systems
- Time requirements and hardware needs
- Suitable social organization of the classroom
- Personal and social consequences

Assess your subject-related digital competencies in the area of presentation!
Please indicate to what extent you agree with the following statements or competency descriptions.

Item code	Item text (rating scale: 1 — *I cannot do this at all.* to 8 — *I can do this perfectly.*).
PRE_DTA	I can describe **technical approaches** to digital presentation.
PRE_DOP	I can describe **opportunities** related to digital presentation.
PRE_ATA	I can apply **technical approaches** to digital presentation.
PRE_AOP	I can utilize **opportunities** related to digital presentation.
PRE_DSD	I can describe digital presentation forms and media used in **scientific disciplines**.
PRE_ASD	I can create and present presentations using digital presentation media in contexts of **scientific disciplines**.
PRE_DPA	I can describe **pedagogical aspects** regarding the advantages and disadvantages of using digital presentations in the classroom.
PRE_DPU	I can describe the **purpose of using** digital presentation techniques in teaching.
PRE_DSR	I can describe **subject-specific didactic requirements** for the use of digital presentation techniques in the classroom.
PRE_DTM	I can describe possible effects of the use of digital presentation techniques on **teaching methods**.
PRE_PLL	I can plan **lessons** in which digital presentation media and forms are integrated, taking into account appropriate modes of (social) interaction and social organization of the classroom.
PRE_COL	I can conduct **lessons** in which digital presentation media and forms are integrated, taking into account appropriate modes of (social) interaction and social organization of the classroom.

Table D.22
Item stem and item texts in the competency area of communication/collaboration (English translation).

Competency area *Communication and Collaboration*

With competencies from the **competency area of communication and collaboration**, you are able to use digital tools to plan synchronous or asynchronous work by individuals or groups towards a common goal and to implement it with learners. To do this, you can create and edit shared files or products, create and manage shared data collections and systematically organize user permissions.

I. **Technical approaches** to digital communication and collaboration include, for example:
- Software for shared text and data processing (e.g. Office 365, Google Docs, Etherpad)
- Shared cloud storage (e.g. Dropbox, OneDrive, school cloud)

II. **Opportunities** related to digital communication and collaboration include, for example:
- Provision of information, learning materials, and assignments
- Synchronous or asynchronous shared document processing
- Collaborative data editing and management
- Exchange via learning platforms

III. In **scientific disciplines**, digital communication and collaboration include, for example:
- Shared lab notebooks
- Joint projects in which your own computing resources are automatically shared with others
- Collaborative document processing for publications
- Communication with (inter)national colleagues
- Knowledge organization and structuring, e.g. via wikis

IV. **Pedagogical aspects** to consider when using digital communication and collaboration in the classroom are, for example:
- Time requirements
- Software and hardware needs
- Suitable social organization of the classroom and forms of collaboration
- Data security and privacy
- Personal and social consequences

Assess your subject-related digital competencies in the area of communication and collaboration!
Please indicate to what extent you agree with the following statements or competency descriptions.

Item code	Item text (rating scale: 1 — *I cannot do this at all.* to 8 — *I can do this perfectly.*).
COM_DTA	I can describe **technical approaches** to digital communication/collaboration.
COM_DOP	I can describe **opportunities** related to digital communication/collaboration.
COM_ATA	I can apply **technical approaches** to digital communication/collaboration.
COM_AOP	I can utilize **opportunities** related to digital communication/collaboration.
COM_DSD	I can describe digital communication and collaboration methods used in **scientific disciplines**.
COM_DPA	I can describe **pedagogical aspects** regarding the advantages and disadvantages of using digital communication and collaboration in the classroom.
COM_DPU	I can describe the **purpose of using** digital communication and collaboration in the classroom.
COM_DSR	I can describe **subject-specific didactic requirements** for the use of digital collaboration and communication in the classroom.
COM_DTM	I can describe possible effects of the use of digital collaboration and communication on **teaching methods**.
COM_PLL	I can plan **lessons** in which digital collaboration and communication are integrated, taking into account appropriate modes of (social) interaction and social organization of the classroom.
COM_COL	I can conduct **lessons** in which digital collaboration and communication are integrated, taking into account appropriate modes of (social) interaction and social organization of the classroom.

Table D.23
Item stem and item texts in the competency area of information search and evaluation (English translation).

Competency area *Information Search and Evaluation*

With competencies from the **competency area of information search and evaluation**, you are able to use digital tools to obtain, organize, and assess information on given topics or for problem-solving purposes. This includes defining search and research objectives, integrating information from various sources, and evaluating it according to digitalization-related quality criteria.

I. **Technical approaches** include the application of search strategies such as:
- Selection of suitable search engines
- Combination of search terms
- Use of advanced search functions on library websites and databases

Relevant digitalization-related **quality criteria** include, for example:
- The influence of ranking algorithms on search results
- Server locations
- Unclear authorship and creation dates

II. **Opportunities** related to digital information search and evaluation include, for example:
- Obtaining information from digital information sources (reference works, journals, databases)
- Structuring information with digital tools
- Evaluation of information according to (digitalization-related) quality criteria

III. In **scientific disciplines**, subject-specific digital information sources include, for example:
- Spectral or gene databases
- Scientific journals
- Information portals

These can be assessed using digitalization-related quality criteria relevant to the respective scientific discipline.

IV. **Pedagogical aspects** to consider when using digital information search and evaluation of digital information sources in the classroom include, for example:
- Access to digital information sources
- Time requirements and hardware needs
- Access restrictions
- Suitable social organization of the classroom
- Personal and social consequences

Assess your subject-related digital competencies in the area of information search and evaluation!
Please indicate to what extent you agree with the following statements or competency descriptions.

Item code	Item text (rating scale: 1 — *I cannot do this at all.* to 8 — *I can do this perfectly.*).
ISE_DTA	I can describe **technical approaches** to digital information search and evaluation.
ISE_DOP	I can describe **opportunities** related to digital information search and evaluation.
ISE_ATA	I can apply **technical approaches** to digital information search and evaluation.
ISE_AOP	I can utilize **opportunities** related to digital information search and evaluation.
ISE_DSD	I can describe digital information search and evaluation used in **scientific disciplines**.
ISE_ASD	I can conduct an information search and evaluation in accordance with quality criteria from **scientific disciplines**.
ISE_DPA	I can describe **pedagogical aspects** regarding the advantages and disadvantages of using digital information search and evaluation in the classroom.
ISE_DPU	I can describe the **purpose of using** digital information search and evaluation in the classroom.
ISE_DSR	I can describe **subject-specific didactic requirements** for the use of digital information search and evaluation in the classroom.
ISE_DTM	I can describe possible effects of the use of digital information search and evaluation on **teaching methods**.
ISE_PLL	I can plan **lessons** in which digital information search and evaluation are integrated, taking into account appropriate modes of (social) interaction and social organization of the classroom.
ISE_COL	I can conduct **lessons** in which digital information search and evaluation are integrated, taking into account appropriate modes of (social) interaction and social organization of the classroom.

Table D.24
Item stem and item texts in the competency area of data acquisition (English translation).

Competency area *Data Acquisition*

With competencies from the **competency area of data acquisition**, you are able to use digital tools to collect data by entering (measurement) data, digitizing analog data, creating images and films, using probes, sensors and software applications, as well as by extracting measurements from documentation media such as images or video recordings.

I. **Technical approaches** include digital measurement systems …
- Which record and digitize measured values, such as radiation, measurement data of important bodily functions.

The measurement characteristics, such as measurement range, measurement accuracy, resolution, measurement frequency per time unit (sampling rate), application areas, limitations, must be taken into account and the measurement system must be calibrated and adjusted.

II. **Opportunities** related to digital data acquisition include, for example:
- Use of computerized data acquisition systems
- Use of integrated sensors in mobile devices (e.g. accelerometers)
- Use of external sensors with mobile devices (e.g. thermal imaging cameras, pH sensors, fitness trackers)
- Video analysis of movements

III. In **scientific disciplines**, digital data acquisition includes, for example:
- Video analysis of impact tests
- Recording of heart rate
- Measurement of pH values

IV. **Pedagogical aspects** to consider when using digital measurement systems in the classroom include, for example:
- Availability of measurement systems
- Time requirements and hardware needs
- Options for displaying measured values
- Suitable social organization of the classroom
- Personal and social consequences

Assess your subject-related digital competencies in the area of data acquisition!
Please indicate to what extent you agree with the following statements or competency descriptions.

Item code	Item text (rating scale: 1 — *I cannot do this at all.* to 8 — *I can do this perfectly.*).
DAQ_DTA	I can describe **technical approaches** to digital data acquisition.
DAQ_DOP	I can describe **opportunities** related to digital data acquisition.
DAQ_ATA	I can apply **technical approaches** to digital data acquisition.
DAQ_AOP	I can utilize **opportunities** related to digital data acquisition methods.
DAQ_DSD	I can describe digital data acquisition used in **scientific disciplines**.
DAQ_ASD	I can digitally record measurements for questions relating to **scientific disciplines**.
DAQ_DPA	I can describe **pedagogical aspects** regarding the advantages and disadvantages of using digital data acquisition in the classroom.
DAQ_DPU	I can describe the **purpose of using** digital data acquisition in the classroom.
DAQ_DSR	I can describe **subject-specific didactic requirements** for the use of digital data acquisition in the classroom.
DAQ_DTM	I can describe possible effects of the use of digital data acquisition on **teaching methods**.
DAQ_PLL	I can plan **lessons** in which digital data acquisition is integrated, taking into account appropriate modes of (social) interaction and social organization of the classroom.
DAQ_COL	I can conduct **lessons** in which digital data acquisition is integrated, taking into account appropriate modes of (social) interaction and social organization of the classroom.

Table D.25
Item stem and item texts in the competency area of data processing (English translation).

Competency area *Data Processing*

With competencies from the **competency area of data processing**, you are able to structure, process and analyze data using digital tools. These tools can be used to filter data, calculate new variables, prepare datasets, conduct statistical analyses, and merge datasets from different sources.

I. **Technical approaches** to digital data processing include, for example:
- Spreadsheet programs (e.g. Excel)
- Use of databases (e.g. for data filtering and calculations)
- Statistical software for data analysis
- Image and video editing software (e.g. Photoshop)
- Software for converting data formats

II. **Opportunities** related to digital data processing include, for example:
- Conversion of data and data formats
- Export and import of digital data of different data types and encodings
- Protection and anonymization of personal data
- Preparation of data for the calculation of new variables
- Data analysis

III. In **scientific disciplines**, digital data processing includes, for example:
- Processing of large datasets (big data analysis)
- Determination and extraction of curve maxima (e.g. sound levels, acceleration data)
- Concentration calculations from color measurements (colorimetry)
- Calculation of measurement uncertainties (e.g. standard error, scatter)
- Concentration calculations from substance quantities and volumes

IV. **Pedagogical aspects** to consider when using digital data processing in the classroom include, for example:
- Time requirements
- Software and hardware needs
- Data security and data protection
- Suitable social organization of the classroom
- Personal and social consequences

Assess your subject-related digital competencies in the area of data processing!
Please indicate to what extent you agree with the following statements or competency descriptions.

Item code	Item text (rating scale: 1 — *I cannot do this at all.* to 8 — *I can do this perfectly.*).
DAP_DTA	I can describe **technical approaches** to digital data processing.
DAP_DOP	I can describe **opportunities** related to digital data processing.
DAP_ATA	I can apply **technical approaches** to digital data processing.
DAP_AOP	I can utilize **opportunities** related to digital data processing.
DAP_DSD	I can describe digital data processing used in **scientific disciplines**.
DAP_DPA	I can describe **pedagogical aspects** regarding the advantages and disadvantages of using digital data processing in the classroom.
DAP_DPU	I can describe the **purpose of using** digital data processing in the classroom.
DAP_DSR	I can describe **subject-specific didactic requirements** for digital data processing in the classroom.
DAP_DTM	I can describe the effects of using digital data processing on **teaching methods**.
DAP_PLL	I can plan **lessons** in which digital data processing is integrated, taking into account appropriate modes of (social) interaction and social organization of the classroom.
DAP_COL	I can conduct **lessons** in which digital data processing is integrated, taking into account appropriate modes of (social) interaction and social organization of the classroom.

Table D.26
Item stem and item texts in the competency area of simulation and modeling (English translation).

Competency area *Simulation and Modeling*

With competencies from the **competency area of simulation and modeling**, you are able to create computer-aided models and use existing digital simulations purposefully to support scientific inquiry and communication processes. You are also able to assess the limitations and potential of models and simulations in the scientific inquiry process.

I. **Technical approaches** to digital simulation and modeling include, for example, applications with functionalities such as:
- Mathematical modeling, and model description with variables
- Specification of output formats (e.g. diagrams or datasets)

II. **Opportunities** related to digital simulation and modeling include, for example:
- Generation of data during the scientific inquiry process (e.g. using spreadsheet software or simulations).
- Comparison of simulated data with experimentally obtained data (e.g. using spreadsheet software).
- Illustration and exploration of scientific and technical contexts using available simulations.

III. In **scientific disciplines**, digital simulation and modeling include, for example:
- Predicting developments (e.g. climate models, weather forecasts, vaccine development)
- Comparison of simulated data with experimentally obtained data (e.g. crash tests)
- Visual representation of scientific phenomena and scientific inquiry

IV. **Pedagogical aspects** to consider when using simulation and modeling tools in the classroom are, for example:
- Suitability for the target group
- User-friendliness
- Attractiveness of the user interface
- Clarity of instructions and learning objectives
- Suitable social organization of the classroom
- Personal and social consequences

Assess your subject-related digital competencies in the area of simulation and modeling!
Please indicate to what extent you agree with the following statements or competency descriptions.

Item code	Item text (rating scale: 1 — *I cannot do this at all.* to 8 — *I can do this perfectly.*).
SIM_DTA	I can describe **technical approaches** to digital simulation and modeling.
SIM_DOP	I can describe **opportunities** related to digital simulation and modeling.
SIM_ATA	I can apply **technical approaches** to digital simulation and modeling.
SIM_AOP	I can utilize **opportunities** related to digital simulation and modeling.
SIM_DSD	I can describe digital simulation and modeling used in **scientific disciplines**.
SIM_DPA	I can describe **pedagogical aspects** regarding the advantages and disadvantages of using digital simulation and modeling in the classroom.
SIM_DPU	I can describe the **purpose of using** digital simulations and modeling in teaching.
SIM_DSR	I can describe the **subject-specific didactic requirements** for the use of digital simulations and modeling in the classroom.
SIM_DTP	I can describe the effects of the use of digital simulation and modeling on **teaching methods**.
SIM_PLL	I can plan **lessons** in which digital simulations and/or modeling are integrated, taking into account appropriate modes of (social) interaction and social organization of the classroom.
SIM_COL	I can conduct **lessons** in which digital simulations and/or modeling are integrated, taking into account appropriate modes of (social) interaction and social organization of the classroom.

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