MedienPädagogik
Zeitschrift für Theorie und Praxis der Medienbildung
www.medienpaed.com ISSN 1424-3636

Which Digital Competences Should All Future STEM Teachers Acquire in Initial Teacher Education?

Using a Delphi Study to Elicit Expectations for Innovating Teacher Education in a Regional Context

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Abstract

Given the growing demand for digital competences among teachers, universities need to consider what should be taught in the initial phase of teacher education. This raises the problem that general frameworks for digital competences need to be specified for specific target groups. The following questions arise: What digital competences are expected of future teachers? What level of these competences is expected? This article addresses these questions using a two-stage Delphi study for the target group of future secondary school teachers of STEM subjects in a regional context. In the first Delphi stage, an online survey was used to gather the expectations of N = 37 stakeholders, including professors of STEM subjects and subject education, as well as practicing teachers, and representatives of the educational administration, based on existing competence descriptions. In the second stage, expectations regarding the level of selected competences were clarified in group discussions with a subgroup of stakeholders (N = 18). The results show that expectations regarding digital competences are broadly consistent (first stage), but that primarily basic competences directly related to coping with professional situations are expected (second stage). On the one hand, this results in concrete focal points for opportunities to learn in university teacher education; on the other hand, the results raise questions about the orientation of fundamental requirements in teacher education. Beyond the specific findings, the article illustrates how the Delphi study can be used as a method in combination with theory-based criteria to specify general frameworks for teacher competences for specific target groups and regional contexts.

Pankrath, Rouven, Juliane Sperling, and Anke Lindmeier. 2026. «Which Digital Competences Should All Future STEM Teachers Acquire in Initial Teacher Education? Using a Delphi Study to Elicit Expectations for Innovating Teacher Education in a Regional Context». *Medien-Pädagogik* (Occasional Papers): 145–180. https://doi.org/10.21240/mpaed/00/2026.05.11.X.

Welche digitalen Kompetenzen sollten alle zukünftigen MINT-Lehrkräfte in der ersten Phase der Lehrkräftebildung erwerben? Durchführung einer Delphi-Studie zur Ermittlung der Erwartungen an die Lehrkräfteausbildung in einem regionalen Kontext

Zusammenfassung
Angesichts des wachsenden Bedarfs an digitalen Kompetenzen von Lehrkräften müssen sich die Hochschulen damit befassen, welche Kompetenzen in der ersten Phase der Lehrkräftebildung vermittelt werden sollen. Dabei tritt das Problem auf, dass allgemeine Beschreibungen für digitale Kompetenzen für spezifische Zielgruppen konkretisiert werden müssen. Daraus ergeben sich folgende Fragen: Welche digitalen Kompetenzen werden von angehenden Lehrkräften erwartet? Welches Niveau wird für diese Kompetenzen erwartet? In diesem Artikel werden die Fragen mittels einer zweistufigen Delphi-Studie für die Zielgruppe von angehenden Sekundarstufen-lehrkräften mit MINT-Fächern in einem regionalen Kontext bearbeitet. In der ersten Delphi-Stufe wurde mittels einer Online-Befragung die Erwartungen von N = 37 Expert:innen, darunter Professor:innen für MINT-Fächer und -Fachdidaktiken, praktizierenden Lehrkräften und Vertreter:innen der Bildungsadministration, entlang von vorliegenden Kompetenzbeschreibungen erhoben. In der zweiten Stufe wurden zudem mit einer Teilgruppe der Expert:innen (N = 18) Erwartungen an das Niveau eines Teils der Kompetenzen in Gruppen diskutiert. Die Ergebnisse zeigen, dass die Erwartungen an digitale Kompetenzen durchgängig breit gefächert sind (erste Stufe), allerdings in erster Linie grundlegende Kompetenzen mit direktem Bezug zur Bewältigung von beruflichen Situationen erwartet werden (zweite Stufe). Daraus ergeben sich zum einen konkrete Schwerpunkte für Lerngelegenheiten in der universitären Lehrkräftebildung, zum anderen wirft das Ergebnis Fragen zur Ausrichtung von grundlegenden Anforderungen in der Lehrkräftebildung auf. Über die konkreten Erkenntnisse hinaus zeigt der Beitrag exemplarisch, wie die Methode der Delphi-Studie in Kombination mit theoriegestützten Kriterien genutzt werden kann, um allgemeine Beschreibungen für Lehrkräftekompetenzen für bestimmte Zielgruppen und regionale Kontexte zu konkretisieren.

1. Introduction

Teacher education and training are complex endeavors as they steadily require adapting to new developments like the digitalization of society. This paper is motivated by a pressing question of initial teacher education: How should we prepare future teachers to act responsibly and competently in a digitalized world, especially in a digitalized school setting?

This question is not simple to answer, and has been widely discussed. Typically, frameworks that model teacher performance or knowledge expectations were provided as answers. However, these are diverse and often abstract, so that they cannot easily be translated into *opportunities to learn* (OtL). For instance, the European Union (EU) developed the DigComp framework (Vuorikari, Kluzer, and Punie 2022) to describe the competences every citizen needs in a digitalized world. DigComp was later specified for teachers as the DigCompEdu framework (Redecker 2017). According to DigCompEdu, teachers should, for example, be able to «manag[e], protect […] and shar[e] digital resources» within a particular educational context (Redecker 2017, 20). Whereas some frameworks also model progressions, for instance, in competence levels (Redecker 2017), others focus on mapping areas of knowledge underlying performance, like the well-cited framework TPACK (technological pedagogical content knowledge) (Koehler and Mishra 2009). TPACK describes implications for teachers' professional knowledge resulting from a changing educational culture due to digitalization and technological innovation.

These examples illustrate that frameworks for the digital education of citizens, learners, or teachers typically provide structured lists of outcome descriptions. Some approaches offer additional resources like a self-assessment tool (Joint Research Centre 2021). While these frameworks outline what future teachers should know or be able to do in a digitalized world, the specific contribution of initial teacher education is still unclear. The challenge is even greater because acquiring digital competences is now considered part of lifelong learning and is rooted in general education. Therefore, it is necessary to systematically align expectations across frameworks, prioritize outcome expectations for initial teacher education programs, and tailor OtL for specific target groups.

In this paper, the problem of what to teach in initial teacher education will be addressed exemplarily for a specific target group and context by a two-stage Delphi study in which the perspectives of teacher-education stakeholders as experts are elicited to substantiate teaching decisions. The outcomes are intended to inform the design of OtL in the regular curriculum at a university's initial STEM teacher education program. Hence, the paper proposes – through an example – a systematic method of transforming abstract outcome expectations for digital teacher competences into specific OtL meaningful within a context.

2. Theoretical background

Various frameworks model which digital competences teachers should hold in a digitalized world. While some frameworks focus more on the professional knowledge teachers need, others describe the structure or development of skills that teachers should have based on that knowledge. Differences can also be found within frameworks outlining the digital competences students should have by the end of general schooling, which can serve as a starting point for teacher education. Although (teacher) education follows different rationales in different educational contexts and political systems, the widely received models and frameworks are suited to synthesize some common ground. We first review work on teachers' digital competences as outcome expectations for teacher education (section 2.1). As a starting point for teacher education, we then address digital competences as expected from students by the end of general schooling (section 2.2).

This article cannot provide a comprehensive review of all models suggested for digital competence on the level of teachers or students, nor discuss differences in underlying theoretical conceptions of education, as attempted elsewhere (for teacher competence models see, e.g., Brüggemann and Frederking (2024) or Sgolik, T. Ziegler, and Kirchhoff (2021); for students, e.g., Lindmeier (2023)). Our review includes frameworks with immediate relevance for the regional context of the study.

2.1 The problem of what to teach, considering frameworks of digital competence for teachers

Recent research suggests that there is a need for more clarity regarding digital competences in general (Peters et al. 2022), as well as more attention to underlying concepts (Spante et al. 2018), since teachers' initial training in digital competences is crucial for mastering the professional demands in the future (Peters et al. 2022). In the light of this research, competences are complex interconnections of knowledge, skills, and attitudes, which are tied to aspects of personal reflection and development (Ferrari 2012; Weinert 2001). To reproduce this structure, we first cover aspects of knowledge (2.1.1) before considering competences as a whole (2.1.2).

2.1.1 Professional knowledge frameworks and extensions

One of the most cited and internationally accepted frameworks for teachers' digital knowledge (Wohlfart and Wagner 2023) is the TPACK framework by Koehler and Mishra (2009). It builds upon Shulman's (1986) well-known model, which describes pedagogical content knowledge (PCK) as an intersection between pedagogical and content knowledge. Koehler and Mishra extended this model by adding a technological knowledge (TK) facet, creating new intersections. The intersection of all three facets, the technological pedagogical content knowledge (TPCK), describes the knowledge a teacher needs to teach the required content pedagogically adequately with the right amount of technology use. Despite explicitly describing teacher knowledge, the TPACK framework is often interpreted in light of teacher competences. However, according to our definition of competences from above, knowledge is just one part, but it can be seen as the foundation for competences to unfold.

Regarding TPACK, although slowly emerging empirical insights (Schmid, Brianza, and Petko 2020; Jin 2019) legitimate critique arises from a theoretical perspective. Here, TPACK is criticized for its focus on the technological aspect for being too narrow by not emphasizing social change through digitalization more thoroughly. Different authors, therefore, suggest replacing the TK component with a broader perspective on digitality, including societal impacts, which results in digitality-related pedagogical content knowledge (DPACK) (Huwer et al. 2019; Döbeli Honegger 2021). However, in those and other extensions of the TPACK framework, the focus on teachers' professional knowledge has been replaced by a broader, but not always clearly defined, concept of competence.

Falloon (2020), for instance, proposed the TDC (teacher digital competency) framework by combining TPACK with the digital competence areas from Janssen et al. (2013). They conducted a Delphi study in central Europe with the explicit aim of mapping requirements for future teachers more holistically than previous knowledge-centered frameworks, including TPACK. Similar to DPACK, TDC argues for a broader understanding of the technological component, including ethical and personal considerations. For instance, teachers should be able to consider «the impacts of digital technologies on people, society and environment» (Falloon 2020, 2460). Falloon takes a closer look at competences but remains rather abstract regarding the overall structure. The model covers a broad range of aspects to support institutions when planning and developing their programs. This high abstraction of general frameworks for digital knowledge and competences typically results in an openness in interpretation. From a teacher education perspective, using the general frameworks to derive concrete OtL is challenging.

2.1.2 Frameworks of competences
In contrast, frameworks of competences like DigCompEdu (Redecker 2017) are more specific and typically detail general digital teaching competences. Within DigCompEdu, six competence areas containing 22 single competences are described. For instance, teachers should «use digital sources and resources for continuous professional development» (Redecker 2017, 19). The competence descriptions can serve as reflection questions for teachers (Joint Research Centre 2021) on how well they are engaged in their professional development, manage digital resources, or empower their learners towards their digital competences. The framework also specifies hypothetical learning progressions for each competence with the potential to design progressive OtL. Although DigCompEdu considers the expected outcomes of teacher education, it is still not subject-specific. In addition, the question remains whether any of the described competences should be prioritized in teacher education, as no prioritization is provided.

An approach more specifically tailored to the needs of professional development in a lifespan perspective is given by Brandhofer and Miglbauer (2020), who created the digi.kompP model as part of Austrian educational policy. It describes digital competences in different categories (e.g., category D: digital teaching and learning; category G: digital school community) as cumulatively evolving. Digital competences at the general school leaving level according to the Austrian K12 standards include competences acquired in computer science lessons (Bundesministerium Bildung, Wissenschaft und Forschung

2013). They are considered the starting point for the development of further competences. For example, teachers are expected to show competences in «planning, execution and evaluation of teaching and learning processes with digital media» (Brandhofer and Miglbauer 2020, 62). Despite short, abstract descriptions of the components, digi.kompP might help prioritize goals for initial OtL in teacher education due to its clear cumulative structure based on expected outcomes of general education in their context. The applicability to other contexts where expectations of general education may be specified differently is open.

Towards empirical insights, there is an urgent need for action on the development of digital competences. For instance, this is supported by the International Computer and Information Literacy Study international (ICILS) 2023 (Eickelmann 2024) or the national educational panel study (NEPS) (Gnambs and Senkbeil 2023). Especially the latter authors were able to show that negative self-selection occurs concerning digital competences among future teacher students: those who study to become teachers are those who have fewer digital competences than their fellow students.

To sum up, acknowledged frameworks on digital teacher competences provide important orientation and outline the big picture of (varying) expectations for digitally well-educated and responsible future teachers. However, the frameworks are often very general and abstract, and therefore, highly open to interpretation (e.g., TDCor TPACK) and typically do not specify requirements for teachers of different subjects (Brüggemann and Frederking 2024) or grades. They also fall short in detailing what should be prioritized in initial, university-level teacher education, and their connection to expected entry conditions is often unclear. However, research has consistently emphasized that theory and practice must be linked through authentic OTL in teacher education (Fernández-Batanero et al. 2022; Røkenes and Krumsvik 2014; SWK 2022) with a strong focus on job-related competences (Braun, Pampel, and Seiss 2021; Schulze-Vorberg et al. 2021), taking into account the prior experiences of future teachers.

2.2 The problem of what to teach considering possible entry conditions

Determining which digital competences future teachers are likely to have already acquired in their prior education is a difficult task in times of digital transformation. In our context, the Standing Conference of the Ministers of Education and Cultural Affairs in Germany (KMK), for example, published guidelines for digital education as a nationwide policy document (KMK 2017). Those guidelines describe key competences that students should acquire in general schooling, like handling information, producing digital media, or solving problems. Specific curricula, however, are still missing.

Typically, such policy documents integrate different prior strands of discourse (Lindmeier 2023). In line with Döbeli Honegger (2017), three aspects of general digital education can be delineated: *utilization competence, media education,* and *computer science education*. *Utilization competence* focuses on effectively navigating and using digital tools and technologies. It includes skills such as operating computers, software applications, and digital devices for various tasks. *Media education* describes self-determined and responsible media use, both from a consuming and producing perspective. This includes critically reflecting on the roles, uses, and functionalities of media to counteract a black box society (Stalder 2016).

Lastly, *computer science education* (CSE) represents the study of the systematic representation, storage, and processing of information. This includes, for example, knowledge of key components of computing systems as an interaction of hardware, software, and networks. An essential concept in CSE is computational thinking (Wing 2006), an overarching concept that includes problem-solving, system designing, and questions of solvability and calculability.

2.2.1 The implications of Computer Science Education (CSE) standards

While specific expectations for utilization competence and media education are still rarely made explicit and hence difficult to delineate (see Lindmeier (2023) for an overview), recent international (K-12 CSE standards, Computer Science Teacher Association (2017)) and national (GeRRI, Verband zur Förderung des MINT-Unterrichts and Gesellschaft für Informatik e. V. (2020), also Gesellschaft für Informatik e. V. (2008, 2016, 2023)) CSE standards for general education offer guidance on the digital competences future teachers may bring to teacher education. However, the standards were initiated within the CSE field, and it remains open whether they will inform national policies. They describe competences in levels, with the GeRRI adopting the rationale of the Common European Framework of Reference for Languages (Little 2005). With levels A1 and A2 as the informal foundation, levels B1, B1+, and B2 describe expectations of general CSE education at secondary schools (Verband zur Förderung des MINT-Unterrichts and Gesellschaft für Informatik e. V. 2020). For example, at level B2, one should be able to use automation techniques within spreadsheets. The K-12 CSE standard uses levels 1A, 1B, 2, and 3A (Computer Science Teacher Association 2017), whereas level 3B serves as the starting point for universities. For example, at level 2, one should «compare tradeoffs associated with computing technologies that affect people's everyday activities and career options» (Computer Science Teacher Association 2017, 18).

With computer science increasingly adopted as a general school subject, standard expectations are consolidating internationally. Nevertheless, caution is advised, and the standards should not automatically be read as the conditions on which OtL in initial teacher education can build. First, computer science as a general school subject is still not mandatory in many countries, including several federal states in Germany

(Eickelmann, Bos, and Labusch 2018; Gesellschaft für Informatik e. V. 2024). Second, adopting a new school subject typically takes time, as it is rolled out progressively, and outcomes may lag further behind expectations because of a shortage of qualified teachers. For instance, in the regional context of Thuringia as a German federal state, the new subject of *media education and computer science* was recently introduced as a mandatory subject with a strong focus on CSE (TMBJS 2018). However, it will take eight years until the graduation of the first cohort of students who studied this subject at school, and, probably, still show broadly varying competences. By now, the starting point at the end of school and among first-year students in Germany is somewhat mixed (Eickelmann 2024; Gnambs and Senkbeil 2023).

General media education frameworks (e.g., Stalder 2016) are less suitable as a starting point for a what-to-teach problem, as they often have less explicit goals and these are usually perceived as cross-cutting tasks.

To sum up, frameworks describing desired outcomes of general education provide important orientations regarding what future teachers may bring to teacher education. However, the diversity of these frameworks and their varied implementation in schools, ranging from mandatory computer science instruction to cross-cutting responsibilities, and sometimes lacking systematic implementation, makes it unclear which entry conditions can be expected in a certain context.

2.3 How to tackle the problem of what to teach

As previously argued, designers of OtL for digital competences in teacher education typically face high uncertainties regarding which digital competences should be prioritized and which entry conditions could be assumed. Nevertheless, first courses for essential digital competences were developed, such as *digi4all* by Romeike et al. (2022). In preparation for the materials for individual self-study for teachers of any subject and grade, the research team synthesized suggestions based on different study programs and computer science courses worldwide (Seegerer and Romeike 2018). This approach is therefore compatible with prior frameworks. Yet, as a one-size-fits-all solution, it is unclear whether it fits a certain context, for instance, regarding prioritization or entry assumptions. Misfits, however, can negatively impair the acceptance and sustainability of any OtL.

Moreover, this and similar (research) approaches reflect a perspective that the development of digital competences for teachers is considered rather an individual problem to be tackled in self-study than an institutional one (Pettersson 2018). This is problematic when considering digitality as a network constantly in reference (Stalder 2016). Teacher education is therefore better understood as a societal task, which is often organized in shared responsibility, as it is in Germany, where an initial phase of teacher education at university is followed by phases of practical teacher training at schools (Cortina and Thames 2013).

One approach to increase involvement and acceptance across distinct institutional responsibilities is incorporating the perspective of relevant stakeholders, including teacher educators, persons from educational administration, and in-service teachers. A Delphi study (Linstone and Turoff 1975) with stakeholders might be an appropriate approach for negotiating the various perspectives regarding what to teach in initial teacher education within a certain regional context.

2.3.1 Delphi studies as a method

Delphi studies are generally characterized as multi-phased structured communications with intermittent feedback to the participants, aiming at eliciting perspectives and working towards consensus solutions to a problem. According to Webler et al. (1991, 256), a «Delphi process is not suited to all types of problems. it [sic] is best suited for those that involve a mixture of scientific evidence and social values», which is certainly given for the questions of future teacher education regarding digital competences. Delphi studies are a flexible approach and typically aim at preserving anonymity to avoid biases due to group dynamics. However, Delphi studies may include face-to-face interactions, for example, to elaborate on reasons for disagreements in prior phases. This modification is known as group-Delphi method (Webler et al. 1991).

To design a Delphi study, the problem and criteria for successful solutions, including conditions for stopping the process, must be clearly defined in advance (Diamond et al. 2014). Further, the participants of a Delphi study must be carefully selected to ensure that the problem to be tackled will be adequately solved due to the broad incorporation of experts of the discipline (Webler et al. 1991). Regarding questions about (future) teacher education within a regional context, relevant stakeholders can be identified via their responsibilities.

Delphi studies have been used before to solve teacher education problems in different contexts, for example, for competences in relation building (Borremans and Spilt 2023), digital competences (Thohir, Jumadi, and Warsono 2022; Mengual-Andrés, Roig-Vila, and Mira 2016; Niederberger et al. 2023), or teaching competences in general (Lerner et al. 2021). Particularly Borremans and Spilt (2023) and Lerner et al. (2021) used a Delphi study to specify and prioritize competences in a certain context of teacher education. Regarding digital competences, Delphi studies have been used for specifying digital competences in elementary education (Niederberger et al. 2023), but not towards teacher competences in the upper secondary level. This type of approach could enrich the international discourse.

Given these aspects, a Delphi study might be suited to tackle the problem of what to teach future teachers in a certain context. It allows for gathering stakeholder perspectives and working iteratively towards a consensus on the most important elements of OtL in initial teacher education.

3. Problem definition and research questions

Based on the argumentation above, we define the problem as follows:

Initial teacher education should offer OtL for digital competences. General frameworks for digital competences are suited to inform about the possible range of objectives for such OtL. Yet, they cannot be read as blueprints for OtL because the descriptions are typically abstract and do not inform about the mutual relevance of different expectations. Also, they do not differentiate for different subjects or grades and often lack suitability to regional educational contexts, for instance, regarding prior digital education. Hence, the problem reads: Which digital competences should be focused on in initial OtL in university-level teacher education for a specific target group within a certain regional context?

This paper aims to describe a systematic method for tackling the problem, using the context of *initial secondary STEM teacher education in the German federal state of Thuringia* as an example. Initial teacher education here refers to the university phase of teacher training. The target group comprises future secondary school STEM teachers. We use a Delphi study with stakeholders to ensure the solution fits the regional context. Based on the argumentation above, we define the following success criteria:

The digital competences to be focused on in OtL in initial teacher education within the regional context should:

- [Criterion C1] be connected to and expand prior knowledge.
- [Criterion C2] be competence-oriented and clearly related to professional demands of teachers.
- [Criterion C3] be consensually considered relevant for all future teachers, especially in a STEM context, by the stakeholders.
- [Criterion C4] be compatible with prior frameworks of digital competences.

Specifically, we answer the following research questions for the exemplary regional context in two Delphi stages:

RQ1: Which digital competences do stakeholders in teacher education within the regional context consensually expect all future STEM teachers to hold?

RQ2: What is the consensually expected level of those competences within the regional context compared to national and international frameworks for general digital competences, such as the GeRRI or the K-12 CSE?

It is important to note that Delphi studies may also fail in any of the questions, indicating that the involved perspectives cannot be aggregated into a consensus. If this happens, a description of the controversial aspects may further the understanding of why stakeholders' perspectives differ and enrich the problem description in future works.

4. Design of the Delphi study

When designing the stages of the Delphi study, we combined different research methods according to the different questions, as depicted in Figure 1. For the first stage and RQ1, a quantitative approach with an online survey based on a synthesis of prior frameworks of digital competences was chosen. A qualitative approach was used in the second stage (RQ2), involving guided, material-based group discussions with the same stakeholders.

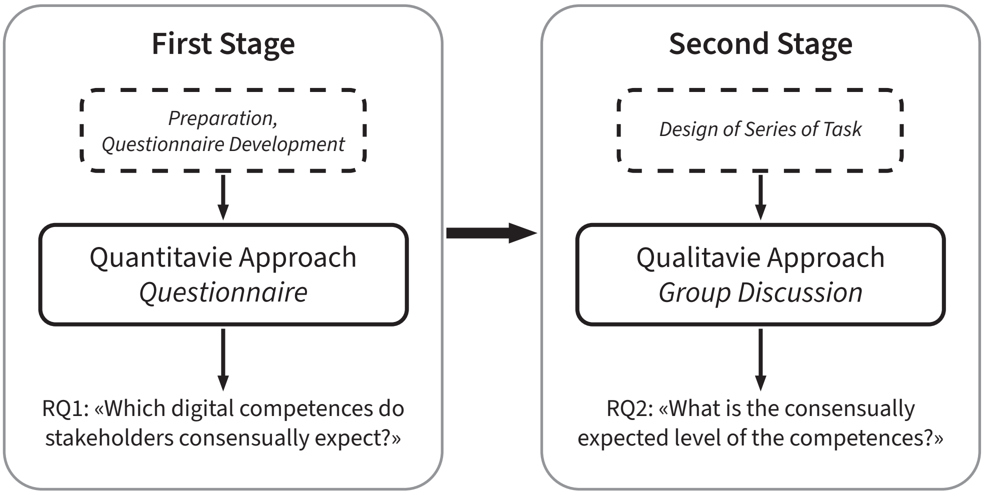


Figure 1: Design of the Delphi study. Schematic illustration.

5. Delphi stage 1: Online survey to answer RQ1

The first Delphi stage aimed at eliciting, in an online survey[1], which competences synthesized from prior frameworks were consensually expected or eventually considered less relevant by the stakeholders [criterion C3]. This should support that the findings can be compared with prior frameworks [criterion C4].

5.1 Development of the instrument

We conducted a content analysis (Früh 2015; Mayring 2015), of frameworks for digital competences and synthesized an initial set of competence areas with competence statements for the survey[2]. We consulted DigCompEdu (Redecker 2017), «teaching in a digital world» (KMK 2017), and the Thuringian curriculum for computer science education at secondary schools (TMBWK 2012). In addition, existing materials for learning and assessment (e.g., the course *digi4all* (Romeike et al. 2022), Janssen et al. (2013),

1 The complete documentation of the questionnaire can be accessed in German in Pankrath and Lindmeier (2025).

2 A preliminary working report of this stage is published in conference proceedings in Pankrath and Lindmeier (2023).

ICILS 2018 (Gerick and Eickelmann 2021)) were examined. By conducting this analysis, we compactly summarized the digital competences expected in these works with eight competence areas (CA, see Table 1). CA1 to CA4 refer to the technical background of everyday technologies in a digitalized world, including artificial intelligence (AI); CA5 and CA6 refer to their societal impact; and CA7 and CA8 refer to general and specific teaching demands. We aimed at delineating topical CA, which worked well for CA1 to CA5. CA6 overlaps with CA2 and CA5, as communication and collaboration depend on networks and are simultaneously shaped by our media culture. Depending on one's reading of subject-specificity, minor redundancies could occur between CA7 and CA8. Within all CA, we incorporated a focus on professional demands [see criterion C2], either related to first-hand teaching situations or with broader relevance for school-related topics. The process ensured that the CA are compatible with prior frameworks [criterion C4].

Competence Area	Headline [number of statements]
CA1	Fundamentals of the functionality and use of a computer [14]
CA2	Fundamentals of the functionality and use of the internet [10]
CA3	Getting, saving, and evaluating data and information [11]
CA4	Understanding, using, and evaluating algorithms [8]
CA5	Fundamentals of media culture and influence of media on daily life [6]
CA6	Communicating through and collaborating with digital technologies [10]
CA7	Designing digital learning environments (in general) [8]
CA8	Using and evaluating subject-specific digital tools [6]

Table 1: Overview of the eight competence areas (CA) with headers and the number of statements included.

We provided the headline and a short introductory text in the survey (see Appendix), as well as 6–14 statements that explicate knowledge (K) and skill (S) for each CA [see criterion C2]. The differentiation of knowledge and skills is also compatible with concepts of competences as complex ability constructs spanning both (Ferrari 2012; Weinert 2001). In contrast, as part of the complex ability constructs, positive attitudes towards digitalization were not included as separate statements, as they were considered non-negotiable for digitally competent teachers. Yet they are not primarily relevant for decisions regarding the focus of OtL in initial teacher education[3] (Christensen and Knezek 2008). Table 2 shows some example statements from CA1, CA2, and CA4.

3 Note that although desired attitudes may not be suited as starting point to decide on the focus of OtL, they should be considered in the design process for OtL and may also serve as an important evaluation criterion.

Label	Statement
CA1_K_bin	Knowledge of the binary number system as the basis of 'digital functioning'
CA1_S_bin	Operating with binary digits, e.g., conversion of binary to decimal numbers, binary addition, subtraction
CA1_K_ipo	Understanding of the computer as a black box according to the IPO principle (input – processing – output)
CA1_S_text	Using software for text editing
CA2_K_ip	Knowledge of the structure and purpose of IP addresses
CA2_S_inet	Acting securely on the Internet (e.g., identifying fake URL as well as spam and phishing emails)
CA4_K_ai	Knowledge of the principles of self-learning algorithms and artificial intelligence
CA4_S_imp	Implement/modify algorithms in a programming language

Table 2: Eight sample statements. Labels indicate their classification within competence areas (CA) and as knowledge (_K) or skill (_S) statements.

In the survey, the participants should evaluate and prioritize the competence statements according to their expected relevance for future STEM teachers. Therefore, we asked them to rate the statements as «*necessary for all teachers on an advanced level*» (3), «*necessary for all teachers on a basic level*» (2), or as «*not relevant for all teachers*» (1). The answer options (3) and (2) were used to express graded expectations, although both answer alternatives clearly indicate that the competence is considered relevant. Alternatively, participants could express that they «*cannot assess the relevance*» (0), if necessary. In addition, the survey included a text field for further suggestions of knowledge or skills relevant to all teachers for each competence area for noting potential further expectations not covered by the given statements.

5.2 Sampling process and sample

According to the problem definition, we sampled stakeholders from different groups of persons responsible for teacher education in the regional context, the German federal state of Thuringia, and a focus on secondary STEM teachers.

Since the University of Jena is the only university that offers programs in initial STEM teacher education at the upper secondary level in Thuringia, we recruited the stakeholders for the subjects of mathematics, computer science, physics, chemistry, and biology as well as those for the general educational sciences at the University of Jena. We identified the subject-education professor responsible for each school subject and asked for their participation and nomination of (up to three) further qualified team members from their group. We explicitly asked to include an in-service teacher, as there is typically one teacher per subject delegated to the university for a few hours to bridge theory and practice. These teachers often have additional duties or experience in in-service teacher training, for example, as mentors or examiners for the second phase of teacher education. Moreover, the professors were asked to recruit one or two representatives responsible for teaching the subject courses[4]. Similarly, two professors of the general educational sciences were asked to nominate up to three persons responsible for the topic of digital competences. Furthermore, we contacted the head of the department responsible for digital education at the educational administration of the federal state and the head of the subordinate institute for (further) teacher training and asked for participation.

		Delphi stage 1			Delphi stage 2	
Group	**Field of expertise**	**Number of responses**	**Response rate**	**ATI M(SD)**	**Number of participants**	**Response rate relative to stage 1**
1 (n=14)	Mathematics (MA)	6	86 %	4.42 (0.59)	4+1*	66 %*
	Computer Science (CS)	8	89 %		5	63 %
2 (n=11)	Biology (BI)	4	80 %	4.00 (0.86)	0	0 %
	Physics (PH)	4	80 %		2	50 %
	Chemistry (CH)	3	60 %		2	67 %
3 (n=12)	Educational Sciences (EdS)	7	70 %	4.46 (0.87)	2	29 %
	Educational Administration (EdA)	5	100 %		2	40 %
Total		37	80 %	4.31 (0.80)	17	46 %

Notes: ATI=Affinity for Technology Interaction scale, range 1–6. *One person participated only in the Delphi stage 2 as a replacement person.

Table 3: Number of participants and response rates per field of expertise per stage; descriptives for the ATI scale.

According to the sampling criterion (responsibility in teacher education), students and in-service teachers without responsibility in teacher education were not considered stakeholders.

4 Note that the subject-education groups (e.g., mathematics education) are part of the department of the corresponding school subject (e.g., faculty of mathematics) and not part of an educational department at this university. Hence, the subject-education professors, who typically are held responsible for the initial teacher education study programs, know their colleagues who are responsible for teaching the subject courses.

This yielded a list of 46 nominees who were invited to participate in the online survey from November 2022 to February 2023. A total of 37 stakeholders participated. The characteristics of the sample and response rates can be found in Table 3.

The overall response rate of 80 % can be considered high and similar for different subgroups introduced to capture possible differences according to the nature of the underlying sciences school subjects or different perspectives on subjects versus general education. In detail, we grouped the subjects of mathematics and computer science due to an overlap in methodological roots; biology, physics, and chemistry can similarly be considered related as representatives of the natural sciences. The educational sciences and administration typically take a more general, subject-overarching view of teachers and teacher education. This yielded three groups of almost equal size, which were intended to be used to analyze results to investigate differences between specific fields of expertise if no consensus emerged.

5.2.1 Affinity for Technology Interaction (ATI) as background variable

Assuming that the digital competences expected by stakeholders for future teachers may be influenced by their technical affinity, we used the Affinity for Technology Interaction (ATI) scale as a background variable (Franke, Attig, and Wessel (2019), sample item: «I like to occupy myself in greater detail with technical systems.»). This established instrument allows us to control whether the subgroups of participants differ in this potentially confounding variable. The scale showed a high internal consistency (Cronbach's $\alpha = .87$). Table 3 displays the means and standard deviations per group and the whole sample (1 = «completely disagree», 6 = «completely agree»). The measured ATI scores were slightly above the mean from the initial study by Franke, Attig, and Wessel (2019). An analysis of variance tested differences between groups, and they were not found to be significant ($F(2,34) = 1.16$, $p = .33$), so the ATI did not differ between groups.

5.3 Methods of analysis and presentation of results for RQ1

To evaluate whether the stakeholders' perspectives show a consensus, we counted the number of answers that indicated relevance (on an advanced or basic level, hence at least code 2) for each statement. In this step, we did not distinguish whether a statement was rated relevant on a basic or advanced level, as both answers express relevance for all teachers (although on different levels).

5.3.1 Overall relevance rating

Consensus was assumed if at least 75 % of the stakeholders indicated relevance, because this is a standard benchmark for consensus in Delphi studies (Diamond et al. 2014).

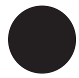
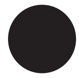
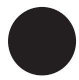
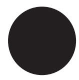
Competence Area	Number of statements rated by at least 75 % of the participants as relevant	
Across all CA	57 of 73	
[CA1] Fundamentals of the functionality and use of a computer	10 of 14	
[CA2] Fundamentals of the functionality and use of the internet	5 of 10	
[CA3] Getting, saving and evaluating data and information	9 of 11	
[CA4] Understanding, using and evaluating algorithms	3 of 8	
[CA5] Fundamentals of media culture and influence of media on daily life	6 of 6	
[CA6] Communicating through and collaborating with digital technologies	10 of 10	
[CA7] Designing digital learning environments (in general)	8 of 8	
[CA8] Using and evaluating subject-specific digital tools	6 of 6	

Table 4: Number of statements consensually considered relevant, additionally visualized as part of the whole, across all CA and for each CA.

The results show that there are competence areas with statements that have been more consensually agreed upon and others that have been less. Yet overall, the stakeholders consensually evaluated a clear majority of statements as relevant (57 of 73, see Table 4).

Table 4 shows that all statements of CA5 to CA8 reached the criterion of 75 %, which were consensually considered relevant. In contrast, there was no consensus for 16 statements in CA1 to CA4, which are more focused on technical aspects of a digitalized world and the basics of algorithms and AI. To illustrate the findings, Table 5 shows the agreement rate for the example statements (see Table 2) for the whole sample of stakeholders and the subgroups.

	Whole Sample	Group 1 MA + CS	Group 2 BI + PH + CH	Group 3 EdS + EdA	p-value for Chi² test
CA1_K_bin	53 %	29 %	44 %	91 %	**$p < .01$**
CA1_S_bin	15 %	7 %	11 %	30 %	$p = .28$
CA1_K_ipo	82 %	69 %	89 %	91 %	$p = .32$
CA1_S_text	100 %	100 %	100 %	100 %	$p = 1$
CA2_K_ip	59 %	57 %	36 %	83 %	**$p < .01$**
CA2_S_inet	100 %	100 %	100 %	100 %	$p = 1$
CA4_K_ai	76 %	67 %	70 %	91 %	$p = .35$
CA4_S_imp	16 %	17 %	18 %	11 %	$p = .90$

Note: Gray cells indicate statements that failed to reach the consensus criterion in the whole sample. **Bold** p-values reached the level of significance.

Table 5: Agreement rate for sample statements for whole sample and subgroups, p-values for tests of difference between groups (Chi²-test).

We analyzed each statement separately to gain insights into why certain statements did not reach a consensus. We examined whether agreement rates differed among the groups with similar fields of expertise (Chi²-tests) or whether these rates were related to the stakeholders' ATI. Among all 73 statements, agreement rates significantly differed between groups for only 6 ($p \leq .05$), all within CA1 to CA4. Table 5 presents two of these. For instance, CA1_K_bin (Knowledge of the binary number system as the basis of 'digital functioning') did not reach the 75 % agreement rate, but agreement rates differed significantly between groups. Notably, the agreement rate was the highest for group 3, even though their professional expertise might be considered the least pertinent to this statement.

5.3.2 Relation between Affinity for Technology Interaction and agreement rates

No significant correlation was observed between agreement rates (aggregated per person and group across all CA) and ATI score (with a significance level of $\alpha = .05$: $\rho_{all} = .153$; $\rho_{group1} = -.061$; $\rho_{group2} = -.159$; $\rho_{group3} = -.025$). So, ATI could be excluded as a possible influence factor.

5.3.3 Written feedback

Additionally, some participants provided annotations in the text fields, which were subjected to deductive-inductive content analysis and coded with the evolving coding scheme (Kuckartz 2018; Mayring 2015). In total, 98 annotations were given, which were used as coding units.

We used deductive codes in line with the framework of Döbeli Honegger (2017) to identify additional competence expectations targeting *utilization competence* (e.g., how to install software or how to handle a projector), *media education* (e.g., impacts of media, social changes, influencing through media), or *computer science* (e.g., working principles of end-to-end encryption).

Moreover, participants used the text fields to provide further annotations, not necessarily indicating competence expectations: Annotations regarding the planned OtL, a specific call to differentiate between teachers of different subjects, meta-criticism on the research approach, including uncertainties regarding specific statements, and other statements that occurred only once (see Table 6). In total, 147 codes were assigned to the 98 units. All coding units were double-coded by two independent raters with high interrater reliability (Cohen's Kappa $\kappa = .81$). Most of the answers (approx. 61 %) suggested constructive feedback and hints for the planned OtL. Those suggestions often explicated specific, relevant practical skills like handling an interactive whiteboard or connecting different devices to projectors.

Codes	Number of assigned units	Example statements[5]
Utilization competence	50	«Skills in dealing with the operation systems in general (Where can I find and change settings?)»
Media education	20	«In the context of types of media and media ethics, I believe it is very important to address the phenomenon of 'fake news' in the digital era.»
Computer science	19	«What is a VPN?»; «Why are mails per se not secure?»
Annotations on the planned OtL	8	«For digitally supported subject-specific teaching, teachers need teaching and learning scenarios based on educational research that they have already been able to apply in their own training and that have proven themselves in classroom practice.»
Meta criticism on research approach including uncertainties	15	«What counts here as programming and algorithms? Also commands in LaTeX, R, Excel etc.? If so, I would differentiate between the [computer] programs here.»
Call for more differentiation regarding the target group of the planned OtL	23	«Some of the points depend on the school subject of the teacher. Everyone should have a basic knowledge, but more in-depth knowledge if it is necessary for its use in instruction.»
Other	12	«The content of subjects will have to change. Teachers should be prepared to accept this and play an active role in shaping it.»

Table 6: Coding categories with number of assigned units and example statements.

5 The written comments were given in German and translated by the authors.

The first Delphi stage shows that stakeholders consensually expect teachers to hold various digital competences across all CA. All 16 cases with lower agreement rates were from the more technical CA1 to CA4. The survey data show that agreement rates for all but six of the more technical statements were similar for the stakeholders from different fields of expertise. Varying perspectives, if any, occur concerning more technical competences distal to teaching demands. Hence, the relevance ratings by the stakeholders were comparatively homogeneous and underpin the high relevance of broad digital competences for future teachers.

6. Delphi stage 2: Material-based group discussion to answer RQ2

The findings of stage 1 do not allow us to infer whether different stakeholders have the same understanding of a competence statement, for example, regarding content or level of expertise. Hence, the second stage aimed to complement the findings and examine whether the stakeholders agree on the levels they expect for competence statements considered relevant. To elicit stakeholders' perspectives in guided materials-based small-group discussions, we used series of tasks[6] (SoT) illustrating levels of requirements for each competence statement.

6.1 Development of materials and conducting of group discussion

The SoT illustrate a possible scale of requirements (from basic to specialized) for each statement. The aim was to determine the level on this scale that all (future) teachers should achieve in terms of competence. Throughout the design process, we focused on tasks related to the professional demands of teachers [criterion C2] (Braun, Pampel, and Seiss 2021; Røkenes and Krumsvik 2014) and also considered discourses on educational expectations in computer science education, for instance, related to constructs like computational thinking (Wing 2006).

We aimed at four to six tasks per series, corresponding to levels of requirements (LR) with increasing complexity. Complexity here refers to two criteria that could occur in combination: First, more complex tasks may require more sophisticated knowledge. Second, they may represent higher cognitive requirements (Anderson and Krathwohl 2001). Figure 2 shows the SoT for CA4_K_ai (Knowledge of the principles of self-learning algorithms and artificial intelligence) as an example.

6.1.1 Adjustment of difficulty level

In each SoT, the basic task was designed to match expectations of standards in general education. This implies that a school student should ideally be able to solve the first task in each series at the end of general education in our context (grades 9–10). In contrast,

6 The catalog with all SoT can be found here: Sperling et al. (2024). Note that the catalog is written in German.

the most complex tasks should represent requirements similar to those expected to be held by a student at the end of the first year specializing in a corresponding study program at the university level. Equidistance of complexity for the tasks was not aimed at. During the development of the tasks, we consulted, according to the targeted range of the series from general to specialized educational level, school and university textbooks (e.g., Diez-Schiefer, Stechert, and van den Berghe (2022), Ernst, Schmidt, and Beneken (2016)), educational standards (e.g., GeRRI (Verband zur Förderung des MINT-Unterrichts and Gesellschaft für Informatik e. V. 2020), K-12 (Computer Science Teacher Association 2017)), examples of competence requirements from other approaches (e.g., DigCompEdu (Redecker 2017)) and documented examples from teacher education (e.g., *digi4all* (Romeike et al. 2022)). This supported content validity and the connection to existing frameworks and prior knowledge [see criteria C4 and C1]. To further strengthen content validity, the tasks were reviewed regarding curricular validity by all authors (author 2 and author 3 studied CS as one of the subjects as upper-level secondary teachers) and an external computer science in-service teacher with a doctoral qualification in CSE. This process should ensure that each task represents the targeted competence level and reflects authentic professional demands. Author 2, a doctoral candidate and emerging computer science educator, led the development of the SoT.

6.1.2 Focus of the developed SoT

For pragmatic reasons of capacity, we decided to focus the second Delphi stage on the competence areas in which OtL still lack in initial teacher education in our context to maximize synergy effects[7]. Hence, we excluded four out of the eight competence areas: CA3 since the University of Jena offers a designated course for data literacy, especially for teacher education; CA5 and CA7 because they show overlap with courses at the educational science department; CA8, as the subject-specific competences are typically catered for in a specific course on teaching with digital tools (e.g., for mathematics). Consequently, SoT were developed for each competence statement from CA1, CA2, CA4, and CA6. Eight SoT cover several statements at the same time.

7 Note that some courses in our initial teacher education already cover certain OtL for digital competences. As practical approaches, the design decisions underlying these OtL are typically not documented and hence it is not clear whether they are aligned with stakeholders' expectations. As the first Delphi stage yielded many competence statements to be relevant for all future teachers, we had to restrict the scope of the second Delphi stage and hence focused the selection according to the problem definition.

SoT (CA_4.03_04) Knowledge of the principles of self-learning algorithms and bias problems

LR 1: Name three everyday situations in which you encounter artificial intelligence.

LR 2: Assign the description to the appropriate concept (weak or strong artificial intelligence):

a) Such systems have human-like cognitive abilities and consciousness. This means that they are not determined to a specific area.

b) The outstanding feature of such systems is the simulation of intelligence. They can only be used in areas in which sufficient qualitative data, for example, possible chess moves or symphonies by different composers, is available for learning the underlying algorithm.

LR 3: Briefly explain the principles of the three main learning methods used in machine learning.

LR 4: Discuss whether decisions made by algorithms are always fair. Consider the phenomenon that some facial recognition software does not recognize female-looking people with dark skin.

LR 5: Discuss whether you would rather use a knowledge-based or a machine learning-based system for a speech recognition app.

Figure 2: Example Series of Tasks for Knowledge of the principles of self-learning algorithms and bias problems (CA4), covering two statements from the online questionnaire at the same time.

6.1.3 Conducting of the group discussions

The group discussions were designed as guided, materials-based small-group discussions, using a standard-setting methodology (Cizek and Bunch 2007) to discuss and determine expected levels for the competence statements. At the beginning of each discussion, the discussion leader (author 1) briefly introduced the results of the previous Delphi stage and highlighted the findings for the focused statements. After introducing and clarifying questions, the participants received the SoT for the statements in focus. The participants were prompted to discuss and agree on an expected level of digital competences represented for each statement by drawing a line to mark the cut-off (bookmark-method to set standards, (Cizek and Bunch 2007; Karantonis and Sireci 2006)). Members of the research team (regularly author 1 and author 2) were present to answer questions, but the research team tried not to interrupt the discussion.

The following data were collected to ensure that discussion results and arguments produced during the discussion are accessible for reconstruction in the data analysis: the annotated materials (SoT with level marking and possibly further annotations), standardized protocols of the outcomes prepared by the second research team member, video recordings of the group discussions, and partly additional unstandardized observation protocols.

In total, we planned six group discussions. For each group discussion, we prepared to discuss a selection of the statements represented as SoT according to the rotation design displayed in Table 7. We aimed to discuss seven SoT per group. Hence, we planned to discuss each of the 31 SoT at least once and certain SoT of competence areas with a low agreement rate in two groups to elaborate further on these subjects, especially the CA4 topics.

SoT Code	SoT for statement was discussed in group discussion						Total number of discussions available per Statement
	GD1	GD2	GD3	GD4	GD5	GD6	
CA_1.01			X				1
CA_1.02		X			(X)		1
CA_1.03_04	X	X					2
CA_1.05_06						X	1
CA_1.07				X			1
CA_1.08				X			1
CA_1.09					(X)		0
CA_1.10	X						1
CA_1.11				(X)			0
CA_1.12_13						X	1
CA_2.01_02_05		X					1
CA_2.03						X	1
CA_2.04		X	X				2
CA_2.06			X				1
CA_2.07				X	(X)		1
CA_2.08_09						X	1
CA_2.10	X						1
CA_4.01					(X)	X	1
CA_4.02					X	X	2
CA_4.03_04	X			X			2
CA_4.06	X	X					2
CA_4.07			X	(X)			1
CA_4.08		X	X				2
CA_6.01					X		1
CA_6.02		X					1
CA_6.03			X				1
CA_6.04	X						1
CA_6.05_06					X	X	2
CA_6.07			X				1
CA_6.08				(X)			0
CA_6.09_10	(X)						0
Total	6	7	7	4	3	7	34

Note: (X) indicates that the SoT was planned to be discussed but omitted due to time constraints.

Table 7: Planned and realized rotation design for the SoT used in group discussions.

For the discussions, we reinvited the stakeholders from the first Delphi stage. Out of 37 participants from the first stage, 17 consented to participate in the second stage (participation rate 46 %, see Table 3, last two columns). Each discussion group had three participants, with no more than one from the same field of expertise. One planned participant from Educational Science (EdS) had to cancel at short notice. Therefore, one person with expertise in mathematics education joined as a replacement. Out of 31 designed SoT, 27 were discussed 34 times in total, with seven SoT being discussed in two different groups and four SoT not discussed at all (see Table 7).

6.2 Methods of analysis and presentation of results

Adapting the bookmark standard-setting method (Karantonis and Sireci 2006), we used the annotated discussion materials and the videography of the discussions to determine the expected levels of competences all teachers should have in terms of the task marked as cut-off. For example, regarding the SoT in Figure 2, both group discussions determined task 4 to represent the expected necessary level for all teachers. One group set the cut-off straight after task 4 without further restrictions. The other group concluded that task 4 was important, but modified task 3 and excluded task 2. This leads to the common expectation of both groups that future teachers should be able to assess the decisions made by algorithms and artificial intelligence.

6.2.1 Mapping the results

To summarize the expected levels across SoT, we mapped the expectations for each SoT against the national (GeRRI) (Verband zur Förderung des MINT-Unterrichts and Gesellschaft für Informatik e. V. 2020) and the US-American K-12 framework for computer science education (K-12 CSE) (Computer Science Teacher Association 2017). The given example corresponds, for instance, to the competence level B2 from GeRRI in the category of sociotechnical contexts and the competence level 3A from K-12 CSE in the category of the cultural impacts of computing. This allows us to communicate the resulting consensually expected levels (tied to the specific SoT) in terms of these frameworks' more general competence levels.

As the stakeholders in some discussion groups have changed the order of tasks within one SoT (observed within nine SoT in total, similar to the given example), we determined the expected level of requirement based on the comments written on the material and arguments given in the discussion.

The expectations could intersubjectively reliably be mapped to both frameworks (two independent coders, Cohens $\kappa = .97$ for GeRRI; Cohens $\kappa = .84$ for K-12 CSE) except for one task from CA1 that could not be mapped to the K-12 CSE levels and was therefore excluded from further investigations regarding this framework.

The distribution of expectations covers all competence levels of GeRRI (see Table 8). Certain requirements in CA4 (Understanding, using, and evaluating algorithms) fall even below the minimum competence of the framework. In contrast, others meet the highest available competence level, which in these frameworks is equivalent to a school leaving level (K12). The expectations for CA6 (Communicating through and collaborating with digital technologies) are located at the upper end of the GeRRI levels, whereas the expectations for CA1 (Fundamentals of the functionality and use of a computer) and CA2 (Fundamentals of the functionality and use of the internet), both with a strong technical focus, concentrate on medium levels. Mapping the tasks to the K-12 CSE results in the same observations.

	Below A1	A1	A2	B1	B1+	B2
CA1	0	2	3	3	0	1
CA2	0	0	2	2	3	1
CA4	5	1	0	0	1	3
CA6	0	0	0	1	1	5

Table 8: Number of SoT with the highest requirement level regarding GeRRI.

	Below 1A	1A	1B	2	3A
CA1*	0	4	3	0	1
CA2	0	0	2	5	1
CA4	5	2	0	0	3
CA6	0	0	1	1	5

Note: * One expectation from CA1 could not be mapped to the K-12 CSE and is hence excluded in this table.

Table 9: Number of SoT with the highest requirement level regarding K-12 CSE.

In conclusion, the levels of digital competences for future teachers that the stakeholders consensually expected in the considered competence area CA1 to CA4 typically do not exceed descriptions of computer science education standards for general education.

7. Discussion

Following the structure of the Delphi study, we first discuss the stages before providing an overall discussion of the whole study.

7.1 Stage 1: Identification of consensually expected competences

Regarding the first research question, «Which digital competences do stakeholders in teacher education within the regional context consensually expect all future STEM teachers to hold?», we received high levels of approval for many of the displayed statements. This suggests a wide range of competences that are consensually expected. Despite a clear prompt to focus on expectations for every STEM teacher, no competences with notably high or low relevance stood out. Hence, priorities cannot be inferred from the stakeholders' perspectives. However, creating an institutional strategy for their development through OtL is challenging without prioritizing specific competences. This dilemma aligns with previous research and is one of the most urgent problems to be solved in teacher education (Peters et al. 2022).

However, the results of the first phase indicate that aspects of digital competences with a strong technological focus might be of relatively lower importance in the considered context. As the participants had varying degrees of technological expertise, including subject specialists in computer sciences, we checked whether the stakeholders' perspectives could be considered homogeneous. This can be assumed since neither the field of expertise nor the Affinity for Technology Interaction was notably related to the agreement rates.

7.2 Stage 2: Determining expected levels of competences

Considering the second research question, «What is the consensually expected level of those competences within the regional context compared to national and international frameworks for general digital competences, such as the GeRRI or the K-12 CSE?», the second stage could elicit specific expectations using cut-offs on a given series of tasks. Mapped against the competence levels of national (GeRRI) and international (K-12) CSE frameworks, we could summarize that the consensually expected levels of digital competences depend on the specific topic. On the one hand, the expected levels regarding CA1 (Fundamentals of the functionality and use of a computer) and CA2 (Fundamentals of the functionality and use of the internet) can be considered equivalent to expectations for grades 8 to 10 of computer science education. Hence, they do not exceed general education expectations at middle grades. On the other hand, expected levels for CA6 (Communicating through and collaborating with digital technologies) were located at the upper end of the competence scale used for CSE standards. Therefore, they can be considered equivalent to grade 12 expectations of general education.

This indicates certain divergences between the expectations set by the CSE standards and those of the stakeholders (which included CSE experts) in our context, as current frameworks of digital professional competences that include progressions (Brandhofer and Miglbauer 2020) position specific professional competences typically above the general educational level.

Another interesting observation was made with the SoT regarding CA4 (Understanding, using and evaluating algorithms), in which tasks covering technical fundamentals of programming and artificial intelligence were classified as not relevant. Conversely, tasks focusing on the impact of computer programs and artificial intelligence were classified as highly relevant on a level comparable to the highest categories of the referred CSE standards. This leads to the question of how crucial knowledge and skills regarding computer programs and artificial intelligence, which CSE frameworks consider fundamental, are for evaluating their impact. Similar patterns were not observed in other CAs discussed.

7.3 The Delphi study as a method to tackle the problem of what to teach in a regional context

The Delphi study proved to be applicable to our problem as it provided valuable results. We now better understand the requirements for OtL in initial teacher education in our regional context. To support this conclusion, we review our given criteria from Chapter 3:

– [Criterion C1] Be connected to and expand prior knowledge: We incorporated this criterion through the consistent use of standards and frameworks during the design of statements and materials and the communication of the results along CSE standards (Computer Science Teacher Association 2017; Verband zur Förderung des MINT-Unterrichts and Gesellschaft für Informatik e. V. 2020).
– [Criterion C2] Be competence-oriented and clearly related to professional demands of teachers: We addressed this criterion by formulating the competences statements and SoT with relevance for teaching and included in-service teachers in the sample. We experienced, however, that anticipating professional demands when developing the SoT was a time-intensive challenge.
– [Criterion C3] Be consensually considered relevant for all future teachers (for STEM subjects) by the stakeholders: In line with typical benchmarks (Diamond et al. 2014), we set the agreement rate to 75 % in stage 1. However, as competence statements are typically abstract and formulated in a general manner, we recognized the risk that high agreement might not truly indicate a consensus on the expected level. By using specific series of tasks (SoT) as illustrations in group discussions, we aimed to clarify levels of requirements and explicit cut-offs. This strategy revealed that, for some areas, expectations consensually did not exceed secondary schooling objectives.

- [Criterion C4] Be compatible with prior frameworks of digital competences: The prior frameworks (Falloon 2020; Redecker 2017) were summarized by the competence areas in this Delphi study, so the results are backward-compatible. In addition, we integrated common national (Verband zur Förderung des MINT-Unterrichts and Gesellschaft für Informatik e. V. 2020) and international (Computer Science Teacher Association 2017) CSE standards, which led to the new insights regarding the level of expected competences in comparison to expectations of general schooling.

7.4 Limitations and transferability

According to the problem definition, our study is tailored to the regional context. This is evident, for example, in the curricular materials used, the sample selection, and the design and evaluation of the SoT. Accordingly, the validity of the Delphi study's results cannot be assumed beyond the regional context. At the same time, teacher education and training, as well as curricular goals for STEM subjects, are highly regulated on the federal level. Thuringia does not stand out as a federal state with specific characteristics in Germany. As this report strives to be transparent regarding the assumptions made during the research process, readers are supported in evaluating whether some findings will likely transfer to their context.

The results rely on the perspectives of the stakeholders involved. Thuringia is small, and all STEM teacher education responsibilities are highly concentrated, so relevant stakeholders can be identified and approached easily, which is also reflected in high response rates. However, it cannot be ruled out that we may have overlooked some relevant stakeholders or that self-selection may have impacted the results.

We had to focus the study on competence areas to determine levels of expectations. As a result, stage 2 had a greater emphasis on technical topics (CA1, CA2, CA4). Expectations related to teaching (a subject) and societal impacts gained less attention. It is open which levels of requirements would be assumed for the areas not in focus.

Finally, the results depend on the SoT used in stage 2 of the Delphi study. These have to be understood as one possible concretization of the competence statements. Although we applied means to ensure their content validity, we cannot assume that they represent all requirements that can be subsumed under each statement. So, further studies should broaden the understanding of which concrete expectations are tied to abstract competence statements.

7.4.1 Transferability of the method

Although we used different scientific research approaches within the Delphi stages, we generally preserved the typical multi-staged design of Delphi studies. We clearly formulated the problem and specified criteria that can be adapted to address similar problems in other contexts, especially when tackling a «what-to-teach problem». However, the iterative nature of the Delphi study requires considerable time and resources, making it impractical for addressing urgent or time-sensitive issues.

7.5 Summary and implications

We started the study to substantiate teaching decisions, specifically to design OtL for digital teacher competences in the regular curriculum at a university's initial STEM teacher education program. The study's results emphasize that consensually expected digital competences are broad and span different areas. This does not allow for prioritizing, which is highly necessary, given the limited time in teacher education.

However, with a focus on selected competence areas, the Delphi study allowed us to determine expected levels of competence, which surprisingly often did not point beyond what is expected as an outcome of grade 12 of general schooling. Although it is debatable whether stakeholders' expectations would rise if CSE standards were fully implemented in general schools, the findings suggest that, for now and in several areas, it might suffice to focus OtL in the focused areas on building digital competences at a general educational level. In other words, the stakeholders' perspectives suggest that addressing deficits in general digital competence that future teachers bring to initial teacher education may solve part of the problem. This could be achieved through bridge courses in the first semesters, in general terms through educational sciences, and in specialized terms through subject education.

If any, digital competences related to the technical background of everyday technologies of a digitalized world were considered slightly less relevant, and the expectations for them did not even exceed the expectations of grade 10 of general CSE. Some frameworks regard general CSE as the basis for developing teachers' advanced digital competences, including an educated interaction with societal implications of digitalization. In this light, our findings may point to a need to discuss whether CSE expectations for general education are overly ambitious or whether expectations for future teachers are set too lenient. Although our study cannot answer this question, it indicates that those responsible for teacher education within a given context may be unaware of the possible conflicts between highly valued advanced competences and missing underlying foundations. However, diverging interpretations of the same general frameworks are not uncommon amongst those sharing education responsibilities. Our study shows how using specific materials and a structured way of communication may elicit possible divergent understandings and help better align OtL in future teacher education.

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CRediT
Conceptualization: *Rouven Pankrath, Anke Lindmeier;* Data curation: *Rouven Pankrath;* Formal Analysis: *Rouven Pankrath, Anke Lindmeier;* Funding acquisition: *Anke Lindmeier;* Investigation: *Rouven Pankrath, Juliane Sperling;* Methodology: *Rouven Pankrath, Anke Lindmeier;* Project administration: *Rouven Pankrath, Anke Lindmeier;* Resources: *Anke Lindmeier;* Supervision: *Anke Lindmeier;* Validation: *Rouven Pankrath, Juliane Sperling, Anke Lindmeier;* Visualization: *Rouven Pankrath;* Writing – original draft: *Rouven Pankrath, Anke Lindmeier;* Writing – review & editing*: Rouven Pankrath, Juliane Sperling, Anke Lindmeier.*

Acknowledgements
This work is part of the THInKI project, founded by the BMBF, number 16DHBKI084. The program aims to support research and teaching towards digital competences, including artificial intelligence. This publication's content reflects the authors' views, who are solely responsible for the scientific findings and interpretations presented. Thanks to Dr. Fabian Graap, who advised during the development and review of the SoT.

Data and investigation instruments availability

The questionnaire for the first Delphi Stage is available under Pankrath, R. and Lindmeier, A. (2025). Dokumentation zum Erhebungsinstrument der ersten Delphi-Stufe im Teilprojekt der Mathematikdidaktik in THInKI. https://doi.org/10.22032/dbt.64973

The catalogue of SoT is available under Sperling, J., R. Pankrath, and A. Lindmeier. 2024. Aufgabenkatalog zu grundlegenden digitalen Kompetenzen mit Lösungsvorschlägen. https://doi.org/10.22032/dbt.62273.

The data supporting the results of this study contain personal data and are therefore not publicly accessible. However, the authors can make them available individually upon justified requests, for example, for further investigation.

Appendix

Introductory texts to the CA as used in the first stage of the Delphi study

CA	Headline and introductory text
CA1	Fundamentals of the functionality and use of a computer
	Computers are the engines of digitalization. We use them every day in various forms (e.g., smartphone, smartwatch, laptop). What does every teacher need to know about computers and how they work? What skills does every teacher need when using computers?
CA2	Fundamentals of the functionality and use of the internet
	As a global, decentralized network, the Internet is of great importance for the globalization and digitalization of our society. What does every teacher need to know about the Internet and how it works? What skills does every teacher need to use the internet?
CA3	Getting, saving and evaluating data and information
	Information has never been as widely and easily available as it is today. This raises questions about the selection, processing and evaluation of information. What does every teacher need to know about information and its digital representation as data? What skills does every teacher need when dealing with data and information?
CA4	Understanding, using and evaluating algorithms
	Algorithms are a core element of digital technologies. Unlike a program, they also exist outside of a programming language. Programming (in the narrower sense) is the implementation of algorithms in a specific programming language. What does every teacher need to know about algorithms and their implementation? What skills does every teacher need when dealing with algorithms?
CA5	Fundamentals of media culture and influence of media on daily life
	The advance of digitalization brings with it new social issues. Media in various forms (e.g. digital publishing services, user-generated content platforms) are changing our culture and the way we live together. What does every teacher need to know about media culture, its history, theories and ethics? What skills does every teacher need when dealing with media?
CA6	Communicating through and collaborating with digital technologies
	Whether privately or professionally, people are increasingly exchanging information digitally and working in digital structures. This development is characterized by social networks in both fields. What does every teacher need to know about communication and cooperation in and through digital technologies? What skills does every teacher need when dealing with technologies for communication and cooperation?

CA	**Headline and introductory text**
CA7	Designing digital learning environments (in general)
	Digitalization also affects schools as a social system and influences the way we teach. This change raises new questions for teachers. What does every teacher need to know to teach in a contemporary way? What skills does every teacher need?
CA8	Using and evaluating subject-specific digital tools
	Subject-specific digital tools (e.g., digital data acquisition in physics, dynamic geometry systems in mathematics, digital lab books in chemistry, digital identification aids in biology, programming environments in computer science) make it possible to experience new ways of working for the respective subject lessons. What does every teacher need to know to master digitally supported subject teaching? What skills does every teacher need for this?