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STEM teachers' self-assessed professional knowledge, attitudes, and self-efficacy for context-oriented, inquiry-based teaching with digital media

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As part of the nationwide DigiProMIN project in Germany, a modular teacher training concept was developed that integrates context-oriented, inquiry-based learning with digital media (including AR and AI) in STEM lessons. The aim is to systematically promote media-related skills among STEM teachers in line with the DigCompEdu framework, based on the TPACK model. In a quantitative survey (N = 71), attitudes, self-efficacy, and self-assessed media-related professional knowledge were measured using standardised scales and analysed according to the principles of classical test theory. Teachers report an overall positive attitude towards digital media, but rate their self-efficacy and competences in areas such as feedback, empowering learners, and media literacy as comparatively low. Correlation analyses reveal significant associations between TPCK/TPK self-efficacy, attitudes, context orientation in chemistry teaching and almost all DigCompEdu competence areas—in particular teaching and learning, digital resources, empowering learners and the promotion of students' digital competences. Regression analyses indicate that context orientation and TPCK-related self-efficacy in particular are key predictors of self-assessed professional competence. Attitudes, by contrast, were not retained as significant predictors. The results underscore that media-related professional knowledge is most pronounced in context-sensitive, subject-specific uses of digital media, accompanied by teachers' confidence in their own professional agency. The study provides implications for the design of evidence-based professional development formats that address both cognitive and affective-motivational aspects and specifically promote the linking of subject content, didactics and technology.

KEYWORDS
attitudes toward digital media, context-oriented teaching, inquiry-based learning, media-related professional knowledge, self-efficacy toward digital media, STEM teacher education

1 Introduction

1.1 Context orientation and inquiry-based learning

Despite extensive research, a persistent gap remains in teaching STEM[1] teaching concepts with real-world relevance (Bünder and Parchmann, 2004; Huntemann et al., 1999; Parchmann et al., 2007). Context-oriented learning offers authentic, interdisciplinary scenarios that deepen students' understanding of socially relevant scientific issues (Bessenrodt-Weberpals, 2007). Topics such as climate change or genetic engineering provide real-life relevance. Addressing them in a differentiated manner helps enhance students' scientific literacy and their ability to engage in socio-scientific issues. The aim is to develop sound technical understanding closely linked to everyday contexts (Huntemann et al., 1999). Moreover, context-oriented learning supports individualised learning paths. The integration of real-life situations, basic concepts, and varied methods fosters self-regulated and cooperative learning (Demuth et al., 2008), strengthening knowledge acquisition and opening pathways to scientific careers regardless of gender or background (Abels and Markic, 2013; Bessenrodt-Weberpals, 2007). Aligned with curricular frameworks and school infrastructure, context-based teaching supports key educational goals outlined by KMK (2020).[2] Teachers face the task of selecting appropriate contexts, aligning them with subject content, and integrating them into interdisciplinary lessons (Demuth et al., 2008). When embedded in curricula, this approach fosters cross-topic links and deepens conceptual understanding (Nerdel, 2017). Learning is viewed as an active, constructive, goal-oriented, and socially embedded process (Reinmann-Rothmeier and Mandl, 2001). Based on this understanding, inquiry-based learning (IBL) encourages learners to engage in inquiry processes that develop both content knowledge and scientific thinking (Otto et al., 2023; Scholkmann, 2016). Learners work on problem-oriented questions within authentic, open, and collaborative settings. IBL emphasizes active learner participation in scientific inquiry (Elsholz et al., 2023; Höttecke, 2010), covering phases such as hypothesis formation, experimentation, and interpretation of results (Bartsch and Müller, 2020; Huber and Reinmann, 2019). Although experimentation and variable control are essential, they can be challenging for younger students (Schwichow and Nehring, 2018). Digital media can support IBL when used purposefully to enhance scientific reasoning (Nerdel and Kotzebue, 2020). Projects like FoLe-digital demonstrate how digital tools can be systematically linked to real-world content (Stinken-Rösner and Abels, 2023). Sustainable implementation requires context-sensitive teacher training (Sailer and Sailer, 2021).

1.2 Functions of digital media and expectations of teachers

The ongoing digitalisation is fundamentally transforming the education system (Blossfeld et al., 2018; KMK, 2020). The overarching aim is to empower learners to participate in a digitalised society in a reflective and self-determined manner (KMK, 2020). Despite improved infrastructure, ICILS 2023 shows that digital innovations are rarely integrated into STEM lessons in a structured, subject-specific way (Eickelmann et al., 2024). Digital media and tools open up a wide range of possibilities for transforming teaching and learning processes, varying in their significance and implementation depending on the subject area (KMK, 2020; Nerdel and Kotzebue, 2020). In the STEM field, they make a central contribution to illustrating scientific concepts by providing (multiple) external representations and expanding experience-based access through immersive technologies such as augmented and virtual reality (Huwer et al., 2019). At the same time, they open up scope for didactic design, for example through the integration of collaborative tools, the use of formative diagnostics to diagnose learning status, or the adaptation of learning paths to individual needs (Lipowsky and Rzejak, 2021). Digital media benefit learning through multimedia and communication tools (Girwidz, 2015; Härtig et al., 2021; Hillmayr et al., 2020). In order to exploit these potentials systematically, integrating digital media more closely into subject-specific teacher training and continuing education is essential (Schultz-Pernice et al., 2017). To achieve this, teachers require specific competences. According to the KMK (2020), teachers should make targeted use of digital resources to design learning processes, analyse data, provide feedback and support learners in an adaptive manner. In addition to subject-specific, pedagogical-psychological and subject-didactic knowledge, (prospective) teachers are increasingly expected to have technical knowledge (Borowski et al., 2010; Lewalter and Walper, 2020; Valtonen et al., 2015). The TPACK model (Koehler and Mishra, 2009) and DigCompEdu (Redecker and Punie, 2017) provide frameworks to reflect on and develop these competencies. Building on the original model, the recently proposed TPACK-in-context framework emphasises the situated and systemic embedding of teacher competences, highlighting the importance of contextual factors for technology use (Brianza et al., 2025; Petko et al., 2025). As artificial intelligence (AI) becomes more prevalent, teachers must also critically engage with such technologies. AI literacy is emerging as a key competence, extending existing frameworks like TPACK (Fengchun and Mutlu, 2024; Hornberger et al., 2023; Long and Magerko, 2020; Mishra et al., 2024). Given the pace of innovation, continuous professional development is essential. However, whether these competences are enacted depends on motivational orientations. Yet, implementation also hinges on teacher acceptance (Lipowsky and Rzejak, 2021). This connects to meta-analytic findings showing that attitudes and self-efficacy are among the strongest predictors of technology integrations (Scherer and Teo, 2019). Studies highlight teacher scepticism and limited adoption of advanced digital tools (Drossel et al., 2019; Vodafone Stiftung Deutschland, 2024; Vogelsang et al., 2019). Nevertheless, much of the existing research still relies on self-reports, although discrepancies between self-assessed and performance-based TPACK measures have been demonstrated (Backfisch et al., 2020; Fabian et al., 2024; Lachner et al., 2019). Subject-specific frameworks emphasise that technology-related competences are shaped not only by knowledge but also by motivational factors (Backfisch et al., 2020; Guzey and Roehrig, 2012). This signals an urgent need for targeted professional development and systematic integration into teacher education (Härtig et al., 2021; Scheiter, 2021). At the same time, it raises important research questions regarding how attitudes, self-efficacy, and

1 Mathematics, computer science, natural sciences.

2 Educational standards of the Standing Conference of the Ministers of Education and Cultural Affairs of the Länder in the Federal Republic of Germany.

context perceptions interact in interdisciplinary, inquiry-based STEM contexts—the focus of the present study. However, little is known about how teachers' attitudes, self-efficacy, and context-related orientations jointly shape their readiness for professional development in interdisciplinary, inquiry-based STEM education. In recent years, a variety of professionalisation measures have been launched to address the challenges of digitalisation and the rapid pace of technological change in STEM education. A common goal across these initiatives is to tailor training to teachers' actual needs, which requires systematically assessing their prior experiences and dispositions at baseline (Zhou et al., 2023). Accordingly, baseline studies serve a dual function: on the one hand, they provide empirical insights into existing gaps in teachers' competences, attitudes, and context orientation; on the other hand, they inform the design and adaptation of subsequent training modules. Crucially, the success of these professional development initiatives depends not only on the competences themselves but also on teachers' motivational orientations and acceptance of innovations (Lipowsky and Rzejak, 2021).

2 Objectives and research questions

To address changing societal and technological demands, science education must prepare learners for academic and professional contexts. This requires learning environments that combine context with digital innovation. IBL is particularly suitable here, as it links interdisciplinary STEM topics with science-oriented ways of working. Within the German national initiative *lernen:digital*, the DigiProMIN project (Cluster 1e, BMBF) develops an innovative teacher training concept that fosters media-related competences in line with professionalisation goals such as subject-specific digital integration, pedagogical reflection, and AI literacy (Redecker and Punie, 2017). The programme (see 3.2), co-developed with IPN Kiel and the University of Hamburg, addresses interdisciplinary topics such as nutrition and health and is implemented at TUM with a focus on secondary biology and chemistry teachers. Its basic module emphasises digitally supported IBL (e.g., fermentation), while the advanced module integrates AI in STEM education. Against this backdrop, it is crucial to understand teachers' initial competence profiles and the factors that shape their professional orientations. To align measurement with the overarching goals of innovation-oriented teacher professionalisation, three constructs were prioritised at baseline: (a) self-efficacy, particularly SE-TPCK/TPK, as a key predictor of teachers' uptake of new, subject-specific media practices; (b) attitudes toward digital media as motivational preconditions for adopting innovative pedagogies; and (c) context orientation as a proxy for teachers' perceived ability to embed digital tools in real-world, subject-specific contexts. This mapping makes the rationale for the baseline assessment explicit and provides boundary conditions against which the intended impact of subsequent training can later be understood (Bortz and Döring, 2023). Within the DigiProMIN framework, these constructs operationalise the programme's professionalisation goals: SE-TPCK/TPK for enacting subject-specific digital practices, attitudes as motivational preconditions for adopting innovative pedagogies, and context orientation to anchor digital tools in authentic, subject-specific contexts (see 3.2). This makes explicit why these variables were prioritised at baseline and how they are expected to connect to the training's later impact. Research indicates that teachers' media-related professional knowledge profiles are often uneven, with technical-organisational skills typically rated higher than pedagogical-didactic ones (Caena and Redecker, 2019; Ghomi et al., 2020). Given that self-efficacy beliefs are domain-specific and shaped by competence perceptions (Petko et al., 2018), it is plausible to hypothesise lower confidence in pedagogical-didactic applications compared to technical ones. Moreover, positive attitudes toward digital media have been linked to higher levels of technology integration (Ertmer and Ottenbreit-Leftwich, 2010). Yet, it remains unclear how these dispositions, competences, and contextual perceptions jointly predict teachers' self-assessed professional knowledge in interdisciplinary, inquiry-based STEM contexts—the very competences that the DigiProMIN training programme aims to foster. Previous research provides a solid foundation for deriving expectations regarding teachers' orientations and competences. Empirical studies indicate that self-efficacy is domain-specific and context-dependent, with variability in strength across technical, organisational, and pedagogical facets; however, consistent directional differences between these domains have not been conclusively established (Schmid, 2023). Consistent with DigCompEdu-based profiles, this pattern provided the rationale for our baseline focus within the DigiProMIN framework, where the training aims to strengthen precisely those pedagogical-didactic facets that teachers tend to rate lower than technical-organisational ones (Caena and Redecker, 2019; Ghomi et al., 2020). Positive attitudes toward digital media have been found to support technology integration (Ertmer and Ottenbreit-Leftwich, 2010), but meta-analytic evidence indicates that self-efficacy beliefs are stronger predictors than attitudes (Scherer and Teo, 2019). Moreover, contextual conditions at school level (e.g., support structures and organisational routines; Eickelmann and Gerick, 2017; Schmid et al., 2017) and individual-level factors such as motivation, PCK, and prior experience have been discussed as relevant for shaping teachers' digital integration (see also Schubatzky et al., 2023 for related findings). Against this background, it can be expected that teachers' competence profiles will show comparatively strong technical confidence and uneven distributions, while pedagogical and contextual factors play a particularly important role in predicting professional orientations in interdisciplinary, inquiry-based STEM contexts. Consistent with prior work, we expected positive associations among the constructs. Meta-analytic evidence highlights self-efficacy as a particularly strong predictor of technology-related outcomes (Scherer and Teo, 2019), while motivation, pedagogical content knowledge (PCK), and prior experience also play important roles (Schubatzky et al., 2023). However, it remains unclear how attitudes, domain-specific self-efficacy (SE-TPCK/TPK), and context orientation jointly relate to teachers' professional knowledge in interdisciplinary IBL. Clarifying these relationships is essential for designing professional development that effectively supports inquiry-based STEM teaching with digital media. By integrating DigCompEdu-based competence profiles with motivational (attitudes, self-efficacy) and contextual (context orientation) variables, this study extends prior DigCompEdu- and TPACK-based research, which has often examined these constructs in isolation. In doing so, it provides a more differentiated perspective on how perceived professional competence in inquiry-based STEM teaching with digital media emerges from the interplay of cognitive, motivational,

and contextual factors. To this end, the present study examines these constructs and formulates the following research questions (RQs) and hypotheses (H):

> *RQ1*: How do STEM teachers assess their attitudes and self-efficacy beliefs regarding the use of digital media for IBL in interdisciplinary teaching?
>
> *H1*: Teachers are expected to report positive attitudes and comparatively higher self-efficacy in technical-organisational than in pedagogical-didactic domains.
>
> *RQ2*: How do STEM teachers assess their self-assessed media-related professional knowledge based on the DigCompEdu competence framework?
>
> *H2*: Teachers' competence profiles are expected to be uneven, with stronger basic/technical than pedagogical-didactic skills.
>
> *RQ3*: What are the correlations between self-assessed media-related professional knowledge and context orientation, attitudes, and self-efficacy regarding digital media?
>
> *H3*: Media-related professional knowledge is expected to correlate positively with attitudes, self-efficacy, and context orientation, with self-efficacy hypothesised to show the strongest association, while contextual/pedagogical factors are also expected to contribute.

Taken together, these considerations motivated the present baseline analysis, which examines teachers' initial attitudes, self-efficacy beliefs, and context orientation in relation to their self-assessed DigCompEdu competences in interdisciplinary IBL. The following section outlines the methodological approach applied to address RQ1–RQ3.

3 Methods

3.1 Participants and data collection

The sample comprises 71 teachers from grammar schools, secondary schools, technical and vocational colleges, all of whom teach chemistry in combination with biology, physics, or mathematics. Participants were primarily from Bavaria (63%), followed by North Rhine-Westphalia (15%), Mecklenburg-Western Pomerania (11%), Baden-Württemberg (8%), and Berlin (1%). Most teachers were aged 31–40 (37%), followed by 25–30 (27%), 41–50 (23%), and 51–60 (13%); only one participant (1%) was younger than 25. The sample included 61% female and 35% male teachers, while 4% did not specify. Most had prior experience using digital media in the classroom and had participated in related training. Since February 2025, the training has been conducted within the DigiProMIN project and typically consists of two modules—a basic one on digitally supported inquiry-based learning and an advanced one on AI in STEM education (see 3.2). Each module is offered as a half-day session (2:00 p.m.–6:00 p.m.), held either at the subject didactics lab or at cooperating schools.

The aim of the study is to examine self-assessed media-related professional knowledge in relation to IBL among STEM teachers (see RQ1–RQ3 in 2.3). The data collection process (see Figure 1) comprises three measurement time points (MTPs): At the beginning (MTP 1), participants complete a digital questionnaire assessing professional knowledge, attitudes, self-efficacy, and demographic/organizational characteristics. This is followed by the first training day, which focuses on the use of digital media in IBL. An optional teaching assignment enables participants to apply their concepts in practice. The second training day addresses the integration of AI in STEM education. Subsequent data collection includes assessments of tool acceptance and usability (MTP 2) and an elaboration task to analyze individual learning processes in greater depth (MTP 3). Participation in the modules was flexible depending on participants' time and interest. As the modules were designed as independent units, participation varied across measurement times, so drop-out rates cannot be meaningfully reported. This article focuses on the data collected at MTP 1.

3.2 Design of the training programme

Although this article reports baseline data only, the training programme is briefly outlined to clarify the study's conceptual embedding and the rationale for the selected constructs. Its design explains why competences, attitudes, and contextual perceptions were assessed at baseline and how they relate to the professionalisation goals. In addition, providing this contextual information helps to avoid the impression of a stand-alone baseline survey and situates the data collection within the broader professionalisation framework of DigiProMIN. Contextual perceptions, attitudes, and self-efficacy beliefs represent boundary conditions that influence teachers' readiness for professional development and are known to moderate subsequent learning outcomes (Ertmer and Ottenbreit-Leftwich, 2010; Scherer and Teo, 2019). Baseline assessments can therefore serve multiple functions: they document participants' initial conditions, help to reduce selection bias, and provide a needs analysis for tailoring module content to participants' disciplinary contexts (Bortz and Döring, 2023; Hallberg et al., 2018). In this sense, the present article reports baseline (MTP1) data only and

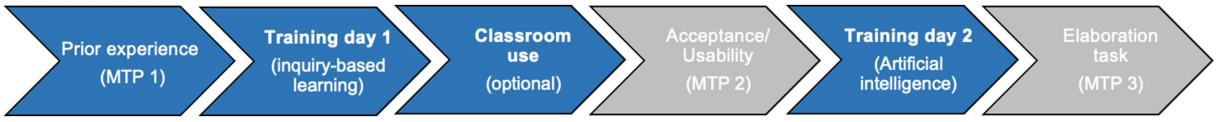

FIGURE 1
Implementation and procedure of data collection with focus on the described sub-study: recording of person characteristics and recording of acceptance and usability as well as processing of one of the three learning environments.

does not make claims about training effectiveness; rather, it provides initial insights that inform subsequent design and evaluation. In addition, the baseline data had two purposes: they supported recruitment and provided a needs analysis to adapt module content to participants' disciplinary contexts.

The training programme builds on current research and the symbiotic implementation strategy (Gräsel and Parchmann, 2004), actively involving teachers in co-design and reflection of digital teaching concepts. It combines elements of inquiry-based, cooperative, and self-regulated learning (Lipowsky and Rzejak, 2021) with a modular structure and input-practice-reflection cycles (Tondeur et al., 2012; van Ackeren et al., 2019). Participants worked collaboratively in small groups (e.g., experimentation, lesson design) and engaged in self-directed phases, such as developing and revising their own digital lesson concepts via Moodle. The blended learning format is grounded in the TPACK model (Graham et al., 2009), aligned with DigCompEdu (Redecker and Punie, 2017), and critically reflects the didactic potential and limitations of digital tools, particularly for inquiry-based STEM teaching. Digital tools serve as both content and medium. Their didactic potential and limitations—especially in inquiry-based STEM teaching—are critically examined. Theoretical models, e.g., SAMR (Romrell et al., 2014) or 5-/6E (Bybee, 2006), were explicitly applied by participants to analyse and redesign their own teaching.

The *basic module* introduces digitally supported experimentation using alcoholic fermentation as an interdisciplinary IBL example. Participants analyse the role of digital tools with the SAMR model (Romrell et al., 2014) and reflect on lesson phases enhanced by media through the 5-/6E model (Bybee, 2006). After hands-on training with apps (e.g., sensors, AR environments), they conduct the fermentation experiment and explore how digital tools support processes such as data collection and interpretation (see Figure 2). Initial lesson concepts tailored to school contexts are developed, presented, and refined on Moodle.

The *advanced module* addresses AI in STEM education, responding to calls for systematic AI literacy in teacher training (Holmes et al., 2019). Building on Module 1, it introduces AI concepts (e.g., neural networks, machine learning) and their educational applications. Teachers design AI-supported materials (e.g., chatbots) using authentic data, practise prompting strategies (Tassoti, 2024), and reflect on opportunities and limitations of AI in fostering inquiry and scientific reasoning.

Accordingly, the programme description not only contextualises the baseline study but also makes explicit how the assessed constructs map onto the programme's professionalisation objectives. This explicit connection justifies the prioritisation of contextual perceptions, attitudes, and self-efficacy in the baseline assessment, as these constructs are foundational prerequisites for acquiring and enacting the professional competencies targeted by the DigiProMIN training modules, including digitally supported inquiry-based teaching. Understanding teachers' initial profiles on these dimensions enables tailored instructional design that addresses motivational and contextual barriers to effective professional learning, thereby furthering the programme's overarching objectives.

3.3 Survey instruments and research method

To address the research questions (see 2.3), a standardised online survey with teachers ($N = 71$) was conducted prior to the training. The survey relied on self-reports of attitudes, self-efficacy, and media-related professional knowledge for IBL. Data were collected via established four-point Likert scales (0 = strongly disagree, 3 = strongly agree). Professional knowledge was assessed via six scales with 22 subscales (3–6 items each). Based on DigCompEdu (Redecker and Punie, 2017), the scales reflect key competence areas for using digital media in IBL (Akademie für Lehrerfortbildung und Personalführung, 2014). An additional five-item scale assessed knowledge of context-oriented chemistry teaching. Attitudes and self-efficacy regarding digital media for IBL were captured using two adapted scales (each with three subscales) based on Ripsam (2023). All scales were grounded in the TPACK model (Graham et al., 2009). Data analysis comprised descriptive statistics, correlation analyses, and regression models based on classical test theory. Stepwise regression was applied in an exploratory manner to identify the strongest predictors of self-assessed competence. This approach is common in exploratory educational research but should be interpreted with caution, as stepwise procedures may capitalise on chance and inflate Type I error rates (Babyak, 2004; Derksen and Keselman, 1992; Whittingham et al., 2006).

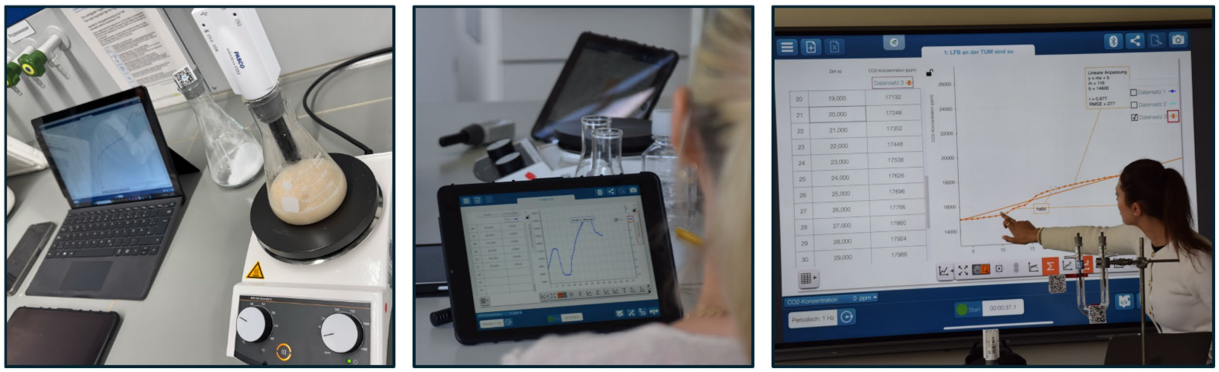

FIGURE 2
Insight into the face-to-face course of Module 1 with guided and independent work phases of the teachers; experimental recording of the CO_2 concentration during alcoholic fermentation with yeast—measurement using a wireless PASCO CO_2 sensor, coupled to a digital evaluation via tablet/laptop.

TABLE 1 Scale documentation of the test instrument on person characteristics (attitudes and self-efficacy) with main and their TPACK subscales, four-point Likert scale (0: "strongly disagree" to 3: "strongly agree"); 71 test persons; number of items per scale (*N*), Cronbach's alpha of the scale (α), mean (M), median (Mdn), and standard deviation (SD).

Scale	*N*	M	Mdn	SD	α	Example item (translated into English)
Attitudes toward digital media (in general)	**16**	**1.89**	**1.81**	**0.52**	**0.90**	"*By using digital media, students can be better motivated to engage in research-based learning in STEM subjects.*" (*E3_dig_TPCK*)
Attitudes toward digital media (TPCK)	7	1.74	1.71	0.49	0.81	
Attitudes toward digital media (TPK)	6	1.95	2.00	0.53	0.82	
Attitudes toward digital media (personal view)	3	2.09	2.33	0.64	0.64	
Self-efficacy toward digital media (in general)	**14**	**1.75**	**1.71**	**0.52**	**0.91**	"*I myself can use digital media sensibly in STEM lessons to promote students' research-based learning.*" (*SW6_dig_TPCK*)
Self-efficacy toward digital media (TPCK)	6	1.61	1.50	0.55	0.81	
Self-efficacy toward digital media (TPK)	6	1.88	2.00	0.53	0.81	
Self-efficacy toward digital media (TK)	2	1.92	2.00	0.86	0.92	

The bold values refer to the main scales along with their corresponding data. Accordingly, the names of the main scales should also be set in bold to ensure consistency and clarity.

4 Results

4.1 Descriptive statistics

Descriptive statistics and item analysis were conducted before reliability testing. Item difficulty mostly ranged from 20–80%. Cronbach's alpha values (0.49–0.96) indicated varying internal consistency: while most subscales showed acceptable to high reliability (e.g., *Professional engagement*, $\alpha = 0.86$), a few (e.g., *Analysing evidence*, $\alpha = 0.49$) displayed lower internal consistency (see Tables 1, 2). Such results are not unusual for short scales, as Cronbach's alpha is sensitive to the number of items and may underestimate reliability in conceptually heterogeneous facets (Edelsbrunner et al., 2025a, 2025b; Tavakol and Dennick, 2011). Therefore, although a future refinement of the scale could be beneficial, the subscales were retained in line with the validated DigCompEdu framework to ensure comparability with previous research. The Cronbach's alpha for the information and media literacy subscale was particularly high ($\alpha = 0.81$). This is likely due to the small number of highly interrelated items ($n = 3$), which suggests a narrow but homogeneous competence facet rather than a broad construct coverage (Tavakol and Dennick, 2011).

The descriptive results reveal moderately positive attitudes toward digital media, with differences across TPACK dimensions and some variation reflected in the standard deviation. The overall attitude (A) score was M = 1.89 (SD = 0.52), with the highest ratings for *Technological-Pedagogical Knowledge* (A-TPK; M = 1.95; SD = 0.53), followed by *Technological Knowledge* (A-Personal View; M = 1.75; SD = 0.52) and *Technological Pedagogical Content Knowledge* (A-TPCK; M = 1.74; SD = 0.49). On the 4-point scale (0 = strongly disagree to 3 = strongly agree), these values are above the scale midpoint (1.5), reflecting generally positive attitudes toward digital media. The consistently low standard deviations suggest a broadly shared positive view. In contrast, perceived self-efficacy (SE) was lower overall (M = 1.75; SD = 0.52), with the lowest scores in SE-TPCK (M = 1.61; SD = 0.55), suggesting values close to the scale midpoint and therefore reflecting undecided responses rather than clear agreement. SE-TPK (M = 1.88; SD = 0.53) and SE-TK (M = 1.92; SD = 0.86) were rated higher. *An example item for SE-TK is:* "*In case of technical difficulties, I usually manage without assistance from others.*" The higher SD in SE-TK suggests variability in technological confidence—some teachers feel secure, while others show uncertainty. Overall, teachers expressed a positive attitude toward digital media in IBL but reported a need for support in didactic integration, especially regarding the interplay of technology, pedagogy, and content. Self-assessments within the DigCompEdu framework indicate generally low to moderate competence overall, as most mean values (except for Digital Continuous Professional Development) fall below the scale midpoint, with variation across areas relevant for digitally supported, student-centred IBL.

The highest self-assessments were reported in *Professional engagement* (Area 1; M = 1.35; SD = 0.57), particularly for *Continuous development* (M = 1.54; SD = 0.75) and *Organisational communication* (M = 1.43; SD = 0.61). While Continuous development lies just above the scale midpoint, the other values in this area remain below it, indicating only modest levels of self-perceived competence. In contrast, *Professional collaboration* received comparatively low ratings (M = 1.01; SD = 0.81), reflecting limited and varied experiences with digital collaboration among peers. Similarly, ratings for *Digital resources* (Area 2; M = 1.29; SD = 0.54) were below the scale midpoint, indicating only modest confidence. Subscales for *Selecting* (M = 1.30), *Creating/Adapting* (M = 1.28), and *Organising/Sharing* (M = 1.31) showed similar scores with low SDs, suggesting consistent but overall restrained responses. Ratings were comparatively low in *Teaching and learning* (Area 3; M = 0.98; SD = 0.57) and *Assessment* (Area 4; M = 1.03; SD = 0.50), with subscales such as *Guidance* (M = 0.87), *Collaborative learning* (M = 0.86), and *Feedback and planning* (M = 0.85) clearly below the scale midpoint. This indicates that teachers generally did not feel confident in these pedagogical areas. *Empowering learners* (Area 5) also received low ratings (M = 0.99; SD = 0.53), particularly *Actively engaging learners* (M = 0.83). The lowest scores were reported in *Facilitating learners' digital competence* (Area 6; M = 0.92; SD = 0.62), especially in *Content creation* (M = 0.72) and *Responsible use* (M = 0.83). Again, these scores are well below the scale midpoint, highlighting a lack of confidence in fostering students' independent media use, though the moderate spread suggests variation across teachers. Teachers rated *Context orientation* in chemistry teaching at a moderate level (M = 1.23; SD = 0.57), suggesting limited but present application of digital media to real-world contexts. In sum, self-efficacy was highest for job-related and technical areas, while pedagogical and learner-centred competences—essential for IBL—showed comparatively lower rating. Taken together, most ratings ranged around or below the scale midpoint, highlighting that while teachers expressed some confidence in Professional engagement and technical aspects, they were far less assured in learner-centred and pedagogical competences.

TABLE 2 Scale documentation of the test for self-assessment of media-related professional knowledge according to DigCompEdu with four-point Likert scale (0: "strongly disagree" to 3: "strongly agree"); 71 test persons; number of items per scale (*N*), Cronbach's alpha of the scale (α), mean (M), median (Mdn), and standard deviation (SD).

Scale	*N*	M	Mdn	SD	α	Example item
Context	**5**	**1.23**	**1.20**	**0.57**	**0.77**	"*I regularly exchange ideas with my colleagues about interdisciplinary teaching concepts.*" *(Kontext3)*
Area of expertise 1: Professional engagement	**12**	**1.35**	**1.33**	**0.57**	**0.86**	"*I use digital media to collaborate with STEM colleagues at my school to develop teaching and learning concepts for research-based learning (e.g., to exchange content, knowledge or opinions).*" *(KollegZ2)*
Organisational communication	3	1.43	1.33	0.61	0.49	
Professional collaboration	3	1.01	1.00	0.81	0.79	
Reflective practice	3	1.39	1.33	0.70	0.73	
Digital continuous professional development	3	1.54	1.67	0.75	0.79	
Area of expertise 2: Digital resources	**16**	**1.29**	**1.25**	**0.54**	**0.90**	"*I use simple internet search strategies to find digital teaching and learning resources for research-based learning in my STEM lessons, for example on educational platforms such as Mebis.*" *(AuswahlR1)*
Selecting	4	1.30	1.25	0.65	0.76	
Creating and modifying	6	1.28	1.33	0.67	0.86	
Managing, protecting, sharing	6	1.31	1.33	0.58	0.74	
Area of expertise 3: Teaching and learning	**15**	**0.98**	**1.00**	**0.57**	**0.93**	"*I systematically select digital technologies (e.g., simulations, interactive online tools and collaborative environments) to achieve the learning objectives in my learning concepts for research-based learning in STEM lessons.*" *(Lehre3)*
Teaching	3	1.28	1.33	0.67	0.68	
Guidance	3	0.87	1.00	0.75	0.86	
Collaborative learning	4	0.86	1.00	0.62	0.78	
Self-regulated learning	5	0.96	1.00	0.57	0.78	
Area of expertise 4: Assessment	**11**	**1.03**	**1.09**	**0.50**	**0.82**	"*I regularly analyse and evaluate different ways of using digital data to optimise the learning process and adapt my own teaching strategies for research-based learning.*" *(AnaLern3)*
Assessment strategies	3	1.12	1.33	0.65	0.65	
Analysing evidence	3	1.24	1.33	0.64	0.49	
Feedback and planning	5	0.85	1.00	0.52	0.68	
Area of expertise 5: Empowering learners	**12**	**0.99**	**1.08**	**0.53**	**0.87**	"*I select digital technologies for research-based learning in a targeted manner and use them to develop integrative learning activities when experimenting in STEM lessons.*" *(Barriere3)*
Accessibility and inclusion	5	1.01	1.00	0.59	0.76	
Differentiation and personalisation	4	1.10	1.25	0.58	0.65	
Actively engaging learners	3	0.83	0.67	0.65	0.76	
Area of expertise 6: Facilitating learners' digital competence	**18**	**0.92**	**1.00**	**0.62**	**0.96**	"*I critically reflect on the extent to which various methods for research-based learning in STEM lessons are suitable for comprehensively analysing media offerings and digital tools in STEM lessons and, if necessary, redesign them accordingly.*" *(AnaRef3)*
Information and media literacy	3	1.04	1.00	0.67	0.81	
Communication	4	1.08	1.25	0.67	0.80	
Content creation	3	0.72	0.67	0.67	0.87	
Responsible use	4	0.83	0.75	0.69	0.87	
Problem solving	4	0.89	1.00	0.67	0.84	

The bold values refer to the main scales along with their corresponding data. Accordingly, the names of the main scales should also be set in bold to ensure consistency and clarity.

4.2 Correlation between personal characteristics and self-assessed media-related professional knowledge

The correlation analysis (see Figure 3) shows a consistent pattern of moderate associations between self-efficacy, attitudes, and the DigCompEdu competence areas. For self-efficacy and attitudes, both overall scales and theoretically central subdimensions (TPCK, TPK) were included, as these are most directly related to subject-specific media use. For DigCompEdu, the established six competence areas were analysed separately, following the validated framework structure. The use of the six DigCompEdu competence areas instead of the more fine-grained subscales was chosen to ensure conceptual clarity and to avoid alpha-error inflation due to excessive multiple testing (Field, 2018). Self-efficacy, particularly TPCK- and TPK-related, shows the most

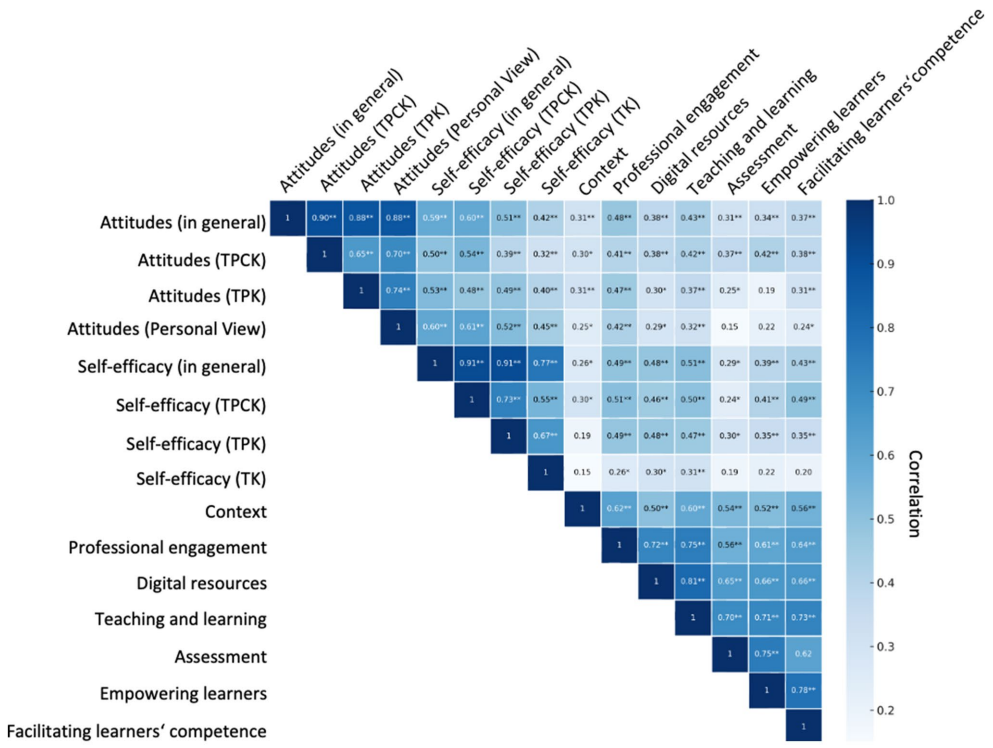

FIGURE 3
Pearson's correlations between central scales on attitudes and self-efficacy with regard to digital media and media-related competences of teachers (N = 71). Significant correlations are marked with $p < 0.05$ (*) or $p < 0.01$ (**). Color intensity indicates the strength of Pearson correlations (lighter colours = weaker associations, darker colours = stronger associations).

consistent associations with DigCompEdu competences, especially in teaching and learning, Professional engagement, and digital resources. Attitudes toward digital media also display significant but weaker links with these areas. Most notably, context orientation reveals the strongest and most consistent correlations across all competence areas, underlining its importance for connecting digital media to real-world contexts. These findings underscore the pivotal role of contextualised, subject-specific instruction in shaping teachers' media-related professional knowledge in inquiry-based STEM teaching. Although strong intercorrelations between individual DigCompEdu competence areas (e.g., *Teaching and learning* and *Assessment*, $r = 0.70^{**}$) were observed, these were not further analysed, since they were beyond the scope of the research questions, which addressed teachers' dispositions and contextual perceptions (see 2.3). In contrast, the DigCompEdu framework served as a descriptive structure for competence areas (Blömeke et al., 2015; Kerres, 2018; Redecker and Punie, 2017).

4.3 Factors associated with self-assessed media-related professional knowledge

Guided by the strongest correlations from the prior analysis, stepwise multiple linear regressions were conducted to identify key predictors for the six DigCompEdu competence areas (see Tables 3–8). All models met the necessary statistical assumptions (normality, homoscedasticity, no multicollinearity: tolerance >0.85, VIF <1.20; no autocorrelation: Durbin–Watson 1.8–2.2).

As Table 3 shows, the final regression model explained just under 50% of the variance ($R^2 = 0.491$, adjusted $R^2 = 0.476$) in Professional engagement. Context orientation in chemistry lessons proved to be the strongest predictor with a standardised beta weight of 0.499, followed by general self-efficacy (0.354).

The model presented in Table 4 showed that around 36% of the variance in the competent use of digital resources could be explained ($R^2_{corr.} = 0.358$). SE-TPCK had a slightly stronger influence ($\beta = 0.394$) than context orientation ($\beta = 0.348$). Both predictors contributed significantly to the prediction. The results suggest that teachers who feel confident in using digital tools for subject-specific teaching and who also use chemistry-specific contexts for digital media in a reflective manner are more likely to use digital resources in their teaching in a targeted manner.

Table 5 shows that more than half of the variance ($R^2 = 0.542$; $R^2_{corr.} = 0.528$) in perceived digital teaching and learning ability was explained by two predictors. With a beta of 0.491, context orientation showed the greatest influence, followed by general self-efficacy (0.410). prorrr.

As Table 6 shows, only context orientation ($\beta = 0.432$) was a significant predictor, explaining 17.5% of the variance in diagnostic and feedback competence ($R^2 = 0.186$; $R^2_{corr.} = 0.175$).

Both context orientation ($\beta = 0.352$) and SE-TPCK ($\beta = 0.345$) significantly predicted empowering learners (see Table 7), explaining 29.7% of the variance ($R^2_{corr.} = 0.297$).

The model for promoting competence among students (see Table 8) delivered the second strongest result with a declared variance of around 46% ($R^2 = 0.459$; $R^2_{corr.} = 0.443$). The influence of context orientation ($\beta = 0.434$) was slightly higher than that of SE-TPCK ($\beta = 0.384$).

Across all six models, context orientation in chemistry teaching consistently emerged as a significant predictor of teachers'

TABLE 3 Regression analysis (stepwise) for professional digital behaviour as criterion variable and context orientation and general self-efficacy as predictor variables (N = 71).

Predictors	*B*	Standard error	Beta	*T*	95% CI for *B*
Context	0.497	0.091	0.499	5.451***	[0.32, 0.68]
Self-efficacy (in general)	0.384	0.099	0.354	3.864***	[0.19, 0.58]

$R^2_{adj.} = 0.476$, $F(2,68) = 32.79$, $p < 0.001$.
***$p < 0.001$.
B, unstandardised coefficient; *β*, standardised coefficient; CI, confidence interval. All subsequent regression tables use the same notation.

TABLE 4 Regression analysis (stepwise) for the use of digital resources as criterion variable and TPCK-related self-efficacy and context orientation as predictor variables (*N* = 71).

Predictors	*B*	Standard error	Beta	*T*	95% CI for *B*
Self-efficacy (TPCK)	0.386	0.101	0.394	3.823***	[0.19, 0.58]
Context	0.332	0.098	0.348	3.375**	[0.14, 0.52]

$R^2_{adj.} = 0.358$, $F(2,68) = 20.52$, $p < 0.001$.
***$p < 0.001$, **$p < 0.01$.

TABLE 5 Regression analysis (stepwise) for teaching and learning with digital media as criterion variable and context orientation and general self-efficacy as predictor variables (*N* = 71).

Predictors	*B*	Standard error	Beta	*T*	95% CI for *B*
Context	0.496	0.088	0.491	5.651***	[0.32, 0.67]
Self-efficacy (in general)	0.451	0.096	0.410	4.718***	[0.26, 0.64]

$R^2_{adj.} = 0.528$, $F(2,68) = 40.21$, $p < 0.001$.
***$p < 0.001$.

TABLE 6 Regression analysis (stepwise) for diagnostic and feedback skills as criterion variables and context orientation as predictor variable (*N* = 71).

Predictors	*B*	Standard error	Beta	*T*	95% CI for *B*
Context	0.378	0.095	0.432	3.977***	[0.19, 0.56]

$R^2_{adj.} = 0.175$, $F(1,69) = 15.81$, $p < 0.001$.
***$p < 0.001$.

self-assessed media-related professional knowledge. SE-TPCK also made a significant contribution in four models. In contrast, attitudes toward digital media were not retained in any model. These findings suggest that media-related professional knowledge is particularly well developed when teachers are both confident in using digital tools and capable of embedding them in subject-specific contexts. Professional development should therefore focus on strengthening both aspects.

TABLE 7 Regression analysis (stepwise) for empowering learners as criterion variable and context orientation and TPCK-related self-efficacy as predictor variables (*N* = 71).

Predictors	*B*	Standard error	Beta	*T*	95% CI for *B*
Context	0.330	0.099	0.352	3.347***	[0.14, 0.52]
Self-efficacy (TPCK)	0.373	0.114	0.345	3.281***	[0.15, 0.60]

$R^2_{adj.} = 0.297$, $F(2,68) = 15.76$, $p < 0.001$.
***$p < 0.001$.

TABLE 8 Regression analysis (stepwise) for facilitating learners' digital competence as criterion variable and context orientation nd TPCK-related self-efficacy as predictor variables (*N* = 71).

Predictors	*B*	Standard error	Beta	*T*	95% CI for *B*
Context	0.471	0.104	0.434	4.527***	[0.27, 0.68]
Self-efficacy (TPCK)	0.427	0.107	0.384	4.001***	[0.22, 0.64]

$R^2_{adj.} = 0.443$, $F(2,68) = 28.796$, $p < 0.001$.
***$p < 0.001$.

5 Discussion

5.1 Differentiated competence profile as reflected in self-assessments

The evaluation of personal characteristics (cf. RQ1) indicates that teachers tend to show moderately positive attitudes towards digital media in education and technological innovation (Ertmer and Ottenbreit-Leftwich, 2010; Petko, 2012). A tendency can be observed between this openness and their confidence in using digital tools for subject-specific purposes. In our data, self-efficacy was higher for TK/TPK and lower for TPCK (integration into subject teaching). This pattern is consistent with discussions that didactic integration poses specific challenges (e.g., Petko, 2012; Tondeur et al., 2012). These findings suggest a reflective rather than resistant stance (Runge et al., 2022). IBL, which requires didactic flexibility, student activation and cognitive engagement, further amplifies these demands (Furtak et al., 2012). The ICILS studies underscore that positive attitudes and technical resources alone are insufficient; the key lies in context-sensitive and pedagogically sound media use (Eickelmann and Gerick, 2017). Teachers highlight the need for support in translating digital tools into subject-specific practice (Petko, 2012; Tondeur et al., 2017). The self-assessments within the DigCompEdu framework (Redecker and Punie, 2017) suggest a differentiated competence profile: ratings for technical-organisational tasks appear higher, while pedagogical-didactic dimensions—especially those related to student-centred learning—were reported somewhat lower, including feedback, collaboration, student activation and the promotion of students' digital competences (Eickelmann et al., 2024; Rubach and Lazarides, 2019). This reflects a tendency to use digital media to deliver content rather than to support open-ended, inquiry-based processes (Eickelmann et al., 2019; Ifenthaler and Yau, 2020). They also align with stage-based models of

competence development (Blömeke et al., 2015). The lowest scores relate to the promotion of students' media literacy, suggesting a lack of systematic media education in current teaching practice (Pietraß and Hannawald, 2008). Nevertheless, teachers rated context orientation in chemistry teaching as moderately positive, indicating some successful integration of real-world relevance via digital media—e.g., through contextualised problems or current applications (Krüger, 2007; Parchmann et al., 2007). Contextualisation is essential for meaningful learning, scientific modelling, and conceptual understanding (Duit and Treagust, 2003; Kaiser and Sriraman, 2006; Schraw and Lehman, 2001). Ultimately, digital media unfold their educational potential primarily through subject-specific, relevant, and authentic learning scenarios rather than in isolation (Krajcik and Blumenfeld, 2005; Ripsam and Nerdel, 2024b). This is particularly relevant for inquiry-based learning, which relies on meaningful contextualisation and active student engagement. Accordingly, continuing education should go beyond technical instruction and address the interplay of content, pedagogy, and technology (Kerres, 2018; Reinmann and Mandl, 2006; Seufert, 2020). At the same time, interpreting the absolute levels of these self-assessments requires caution. Because the scales were not norm-referenced or externally calibrated, the generally modest mean values—often located around the midpoint of the Likert scale—cannot be unequivocally interpreted as low self-assessed competence. Instead, values near the midpoint are more plausibly understood as reflecting undecided responses. This interpretation is supported by the clustering of medians around the scale midpoint, while the relatively broad dispersion of responses suggests heterogeneous self-assessments rather than uniform indecision. Accordingly, relative differences across self-assessed competences provide more robust insights than absolute levels. It is important to emphasise that the present findings are based on self-assessments and therefore reflect perceived rather than objectively measured professional competence. At the same time, such self-assessments offer theoretically meaningful insights into teachers' professional dispositions, including beliefs, confidence, and perceived action readiness, which constitute central components of professional competence models (Blömeke et al., 2015; Kunter et al., 2013). From this perspective, perceived competence represents a relevant predictor of instructional decision-making and the uptake of innovative teaching practices (Bandura, 1977; Ertmer and Ottenbreit-Leftwich, 2010). Building on these differentiated profiles, the following analysis explores how they relate to teachers' attitudes and self-efficacy.

5.1.1 Findings regarding H1 and H2

Both hypotheses were supported. H1 confirmed: teachers reported moderately positive attitudes toward digital media and higher self-efficacy in technical/technological-pedagogical domains (TK/TPK) than in TPCK for subject-specific integration. This pattern aligns with prior work linking attitudes and self-efficacy to technology use while noting lower confidence in didactic integration (Ertmer and Ottenbreit-Leftwich, 2010; Petko, 2012; Tondeur et al., 2017). H2 confirmed: the DigCompEdu self-assessments showed an uneven competence profile—stronger in basic/technical and organisational areas and lower in pedagogical-didactic facets (e.g., collaboration, feedback, student activation), in line with earlier DigCompEdu-based findings (Caena and Redecker, 2019; Eickelmann et al., 2019; Ghomi et al., 2020; Ifenthaler and Yau, 2020).

5.2 Correlative relationships: professional orientations as the key

The correlation analysis between media-related professional characteristics (DigCompEdu), attitudes, and self-efficacy (see RQ3) suggests that cognitive and motivational-affective components of professional competence are related, with correlations in the weak to moderate range. However, studies using performance-based TPCK tests found less consistent relationships (Backfisch et al., 2020; Fabian et al., 2024; Lachner et al., 2019; Schubatzky et al., 2025), highlighting that self-assessments may capture different aspects of competence than objective measures. Professional action is shaped by the interplay of knowledge, beliefs, and context (Blömeke et al., 2015). In line with this, the results demonstrate that positive attitudes and a higher level of confidence in integrating digital tools into subject-specific teaching show statistically significant yet small-to-moderate associations with teachers' perceived professional competence—particularly in areas involving student-centred teaching, diagnostic assessment, and feedback (Bandura, 1977; Scherer et al., 2021). The strongest associations were found between SE-TPCK and DigCompEdu areas, most notably *Teaching and learning* (e.g., guidance, collaborative learning), *Digital resources* (e.g., selecting, creating, and sharing), *Assessment* (e.g., analysing learning evidence, planning feedback), *Empowering learners* (e.g., differentiation, actively engaging learners), and *Facilitating learners' digital competence* (e.g., content creation, responsible use, problem solving), as outlined by Redecker and Punie (2017) and confirmed by Ifenthaler and Yau (2020). These findings highlight SE-TPCK as an important link between content, pedagogy, and technology (Graham et al., 2009; Mishra and Koehler, 2006). Its association with teachers' beliefs about differentiated instruction and student activation underscores its relevance for implementing IBL in STEM contexts (Duit et al., 2012; Reinmann and Mandl, 2006). Moreover, the observed interrelations among DigCompEdu's action-related competence areas suggest that these dimensions should not be treated as isolated but rather as integrated components of broader professional orientations (Ifenthaler and Yau, 2020). However, as the study focused on individual dispositions and contextual variables, these structural relationships between competence areas were not analysed in depth. This limitation resonates with recent work emphasising the situated and systemic embedding of teacher competences (Brianza et al., 2025; Petko et al., 2025). These perspectives highlight that professionalisation efforts must not only target individual competence growth but also address school-level and systemic conditions that shape how teachers can apply digital tools in practice. Despite relying on self-assessments, the patterns align with evidence that such perceptions offer valid insights into professional competence (Kunter et al., 2013). They also reflect the perspective of situated learning theory, which holds that knowledge and beliefs develop in specific school and collegial contexts through meaningful practice (Lave and Wenger, 1991). Teachers with high self-efficacy are somewhat more likely to use digital tools reflectively and to support learning (Ertmer and Ottenbreit-Leftwich, 2010; Ripsam and Nerdel, 2024a). One particularly noteworthy finding concerns the relevance of context orientation. Teachers who embed digital media in real-world, subject-specific contexts report higher levels of media-related professional knowledge—a finding consistently supported by correlation and regression analyses (Bybee, 2006; Elsholz et al., 2023; Jonassen, 2000; Schraw and Lehman, 2001). Context orientation emerged as a consistent predictor across all six DigCompEdu areas, ranging from the use of digital resources

to diagnostic feedback and the promotion of learners' media literacy (Eickelmann and Gerick, 2017; Schmid et al., 2017). SE-TPCK again emerged as a consistent explanatory variable, particularly in competence areas requiring integration of content, pedagogy, and technology (Graham et al., 2009; Mishra and Koehler, 2006). While attitudes foster openness, they did not significantly predict self-assessed media-related professional knowledge as operationalised within the DigCompEdu framework, consistent with the findings of Tondeur et al. (2017). Meaningful digital integration appears to depend more on context-sensitive professional knowledge and instructional relevance than on general enthusiasm (Ertmer and Ottenbreit-Leftwich, 2010; Petko, 2012). In sum, while we did not directly measure reflective and learning-oriented use, the patterns observed indicate that such use is more likely when teachers feel confident in their ability to purposefully align digital tools with pedagogical and content-related goals. Ultimately, digital professionalisation depends more on instructional relevance than enthusiasm for technology (Ifenthaler and Egloffstein, 2020; Kerres, 2018; Seufert, 2020).

5.2.1 Findings regarding H3

H3 was only partially supported. Media-related professional knowledge correlated positively with attitudes and self-efficacy, but effects were weak to moderate and attitudes did not emerge as significant predictors in the multivariate models; instead, context orientation and SE-TPCK were the more consistent explanatory variables, mirroring earlier evidence that pedagogical/contextual factors outweigh general enthusiasm (Ertmer and Ottenbreit-Leftwich, 2010; Tondeur et al., 2017). This convergence holds for self-report data, while studies using performance-based TPCK tests report less consistent relations, suggesting that self-assessments capture perceived confidence/motivation rather than objective knowledge (Schubatzky et al., 2025).

5.3 Implications for research and professionalisation

Effective professional development must address both cognitive and motivational-affective dimensions of teacher competence (Blömeke et al., 2015). To support this, experience-based, reflective, and collaborative learning settings are recommended, as they foster the development of professional beliefs and dispositions—while also acknowledging the limitations of self-assessment data (Moosbrugger and Kelava, 2012). The DigiProMIN project provides an illustrative example. It explicitly integrates digital media into interdisciplinary teaching and fosters SE-TPCK through authentic, context-rich learning opportunities. These include emerging components such as AI literacy, which extend traditional concepts of media competence (Holmes and Tuomi, 2022). Building on the DigCompEdu framework (Redecker and Punie, 2017) and its STEM-adapted version (Ghomi et al., 2020), we use it here as a structural reference for identifying and developing media-related competences in interdisciplinary contexts. Professionalisation should thus not be understood as the mere transmission of knowledge, but as a situated learning process that considers both individual competence development and school-specific conditions (Seufert, 2020). In line with this, future implementations of the training programme are planned in diverse educational contexts, accompanied by a mixed-methods evaluation to examine changes in professional knowledge, beliefs, and behavioural intentions (Blömeke et al., 2015; Moosbrugger and Kelava, 2012). A specific focus will be on evaluating the usability and didactic potential of digital tools such as the yeast AR app in fostering IBL in science education (Buchner and Zumbach, 2020; Karapanos et al., 2018; Ripsam, 2023). The current study also revealed methodological limitations: The extensive number of self-report scales may have led to fatigue effects, potentially biasing the assessment of later-positioned constructs (Gnambs and Kaspar, 2017; Meade and Craig, 2012). As noted, reliance on self-assessments captures perceived rather than actual competence, often reflecting self-efficacy rather than professional knowledge (Fabian et al., 2024; Kotzebue, 2022; Lachner et al., 2019; Schubatzky et al., 2025). Furthermore, two scales showed low internal consistency and should be revised in future surveys. Moreover, the absence of norm-referenced calibration limits the interpretability of the descriptive results. While relative profiles across self-assessed competences can be meaningfully compared, it remains uncertain whether the overall levels observed here represent genuinely low self-assessed competences or are influenced by scale properties and response tendencies such as social desirability. The high correlation between SE-TPCK and professional knowledge may indicate conceptual overlap, yet also points to convergent validity (Blömeke et al., 2015). In addition, the cross-sectional design precludes causal inferences, and the analysis was restricted to MTP1 data from STEM teachers, limiting the generalisability to other subjects and contexts. The sample size was moderate, which may have constrained statistical power. As the regression models were identified using a stepwise procedure, the findings should be considered exploratory rather than confirmatory. Future studies with larger samples and theory-driven model specifications are needed to validate these patterns. Despite their role in fostering openness (Petko et al., 2018), attitudes toward digital media alone were not sufficient to explain variance in professional competence—confirming that contextualised pedagogical knowledge plays a more decisive role (Ertmer and Ottenbreit-Leftwich, 2010; Tondeur et al., 2017). This underlines the need for professional development formats that not only impart knowledge but also create meaningful opportunities for practical experience and positive attitudinal change. Taken together, the findings address RQ1–RQ3 by highlighting that differentiated competence profiles (RQ1), their interrelations with motivational dispositions (RQ2), and the explanatory role of SE-TPCK and context orientation (RQ3) converge in pointing to the need for professionalisation formats that integrate cognitive, motivational, and contextual dimensions—ideally aligned with international frameworks such as DigCompEdu.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval was not required for the study involving humans in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was not required from the participants or the participants' legal guardians/next of kin

in accordance with the national legislation and the institutional requirements.

Author contributions

MR: Writing – original draft, Writing – review & editing. CN: Writing – original draft.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that Generative AI was used in the creation of this manuscript. AI-assisted tools were used only for minor, non-scientific tasks such as improving the linguistic clarity of English passages, checking grammar, and generating simple illustrative draft figures. No AI system was used for data analysis, interpretation of results, or any part of the scientific reasoning. All scientific content, conclusions, and revisions were developed entirely by the authors.

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