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Research paper

# Uniting generic and content-specific instructional quality: A profile analysis of pre-service teachers' learning experiences and its relevance for TPACK development

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A B S T R A C T

Promoting TPACK in teacher education programs is a current imperative. One approach to foster TPACK is focusing on instructional quality (INQ), which offers two perspectives on effective learning experiences: generic and content-specific INQ. Past studies have examined both INQ perspectives separately, whereas our study aims to unite both perspectives by investigating the extent to which their combined influence shapes the development of pre-service teachers' TPACK. Therefore, we first explore heterogeneous experiences with INQ by using latent profile analysis, and second use multi-group latent change models to examine the TPACK development across identified profiles. Our sample consists of 248 pre-service teachers from one German University. We identified heterogeneous profiles reflecting pre-service teachers' varied experiences with both generic and content-specific INQ. Notably, pre-service teachers in profiles defined by high satisfaction with all INQ dimensions also had significant TPACK development, emphasizing the central role of both generic and content-specific INQ to foster TPACK development for pre-service teachers.

## 1. Introduction

One goal of teacher education is that pre-service teachers are digital competent, meaning they acquire both basic and professional digital competence, needed for their future professional tasks (Elstad & Christophersen, 2017; Gottschalk & Weise, 2023; Valtonen et al., 2015). In order to achieve this goal, teacher education has to provide learning environments that support the development of digital competence since these do not develop naturally (Johnson et al., 2023; Rubach, 2024a). Hereby, prior studies highlighted the crucial role of teacher education quality[1] (Kraft et al., 2018) and the need for its evaluation to enhance pre-service teachers' competence development within teacher education (Liu, 2015; Tondeur et al., 2021). Exploring learning experiences in teacher education requires attention to several factors. To begin with, teacher education programs at university offer various learning opportunities. They vary depending on the areas of expertise of the instructors, the program's curriculum, and whether they are mandatory or optional, covering subject content, didactics and educational sciences (Rubach & Hirsch, 2026). However, to our knowledge, little is known about learning experiences that pre-service teachers have within teacher education when it comes to digital education.

Understanding what learning experiences pre-service teachers encounter offers one way to gain insights into how their Technological Pedagogical and Content Knowledge (TPACK), as one aspect of professional digital competence, may develop. Instructional quality (INQ) provides one theoretical perspective on mandatory quality dimensions for effective learning environments that foster competence development; differentiating between generic (e.g., Three Basic Dimensions framework [TBD]; Klieme et al., 2001) and content-specific INQ (e.g., Synthesis of Qualitative Evidence [SQD-model]; Tondeur et al., 2012). Scholars from educational technology (EdTech) who aimed to explain the development of (pre-service) teachers' TPACK, mostly focused on content-specific INQ (Funke et al., 2025; Grassinger et al., 2022). In this study, content-specific INQ refers to dimensions emphasizing the development of digital competence in teacher education guided by the SQD-model, rather than subject-specific pedagogical practices.

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[1] Teacher education in Germany is federally organized and consists of three phases: (1) university-based teacher education, (2) a preparatory service (*Referendariat*), and (3) in-service professional development. The first phase takes place at universities and colleges and is typically differentiated by school type, grade level, and subject area. Following the Bologna Process, programs are accredited and structured according to the European Credit Transfer and Accumulation System (ECTS), usually combine bachelor's and master's degrees, with some programs following the state examination system (*Staatsexamen*). Program duration varies but is often ten semesters (Rubach & Hirsch, 2026).

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Integrating insights from both generic and content-specific INQ perspectives could enhance our understanding of the development of TPACK in teacher education as it provides a broader perspective on what constitutes effective learning environments. However, to our knowledge, the impact of generic and content-specific INQ on competence development have been often investigated separately in empirical studies (Holzberger et al., 2019). As this study aims to describe pre-service teachers' learning experiences in the context of digital education, we focus on both generic and content-specific INQ and its orchestration in teacher education seminars using latent profile analysis. As a second step, we examine the extent to how generic and content-specific INQ dimensions foster the development of pre-service teachers' TPACK.

## 2. Theoretical and empirical background

### 2.1. TPACK as one aspect of (pre-service) teachers' digital competence

There are several definitions of digital competence and related constructs such as information and communication technologies (ICT) literacy or media literacy (Vuorikari et al., 2022). In the context of teacher education, we define digital competence as the combination of knowledge, motivation and situation-specific skills relevant for using ICT effectively in various situations (Rubach, 2024a). Following this definition, digital competence can be separated into basic and professional digital competence (Krumsvik, 2014; Rubach, 2024a). Basic digital competence refers to the general competence needed to navigate everyday life in a digitally mediated society (Ilomäki et al., 2016; Vuorikari et al., 2022), whereas professional digital competence relates to the specific contexts and demands in work-related situations (Rubach, 2024a; Rubach & Lazarides, 2021).

One widely recognized framework of professional digital competence is the TPACK framework (Mishra & Koehler, 2006), which focuses on the knowledge component of competence. It describes three knowledge domains teachers need in order to teach with ICT effectively, i.e., Technological Knowledge (TK), Pedagogical Knowledge (PK) and Content Knowledge (CK). Their interrelationship results in four sub-components which provide the mandatory prerequisite to effectively use ICT in class: Technological Content Knowledge (TCK), Pedagogical Content Knowledge (PCK), Technological Pedagogical Knowledge (TPK) and TPACK (Mishra & Koehler, 2006). Prior research has indicated that TPACK is a meaningful indicator of professional digital competence, as it predicts professional ICT use (Guggemos & Seufert, 2021; Harris et al., 2017; Ottenbreit-Leftwich & Kimmons, 2020). In detail, teachers with strong self-perceived TPACK are able to effectively integrate ICT into their classroom by aligning their choice of technology with both pedagogical objectives and subject matter (Backfisch et al., 2023; Guggemos & Seufert, 2021). Consequently, TPACK is widely used in teacher education and research to evaluate and support pre-service teachers' development of professional digital competence and ICT use. To note is, that the meta-analysis by Fabian and colleagues (2024) indicates that the majority of intervention studies used self-report measures and predominantly addressed TK.

Previous research on pre-service teachers' TPACK has yielded inconsistent results, but indications for the further development of teacher education may be derived. Zinn and colleagues (2022), for example, indicated that pre-service teachers rated themselves at a moderate level in the technology-oriented domains (TK, TPK, TCK, TPACK), but higher in the non-technology domains (CK, PK, PCK). In contrast, Baran and colleagues (2011) found that pre-service teachers are the most confident in CK and TPK, whereas Valtonen and colleagues (2018) reported stronger confidence in CK and PK. The study by Valtonen and colleagues (2020) indicated that PK is not only the area in which pre-service teachers feel the most confident but also the most challenged. Thus, one objective from teacher education research is to examine how TPACK can be fostered in teacher education and which learning experiences support this development (Wilson et al., 2020).

### 2.2. Instructional quality and its matter to support TPACK development

Previous research highlighted the importance of INQ for TPACK development (Gerke & Wegner, 2022; Sun et al., 2017). INQ captures how learning is facilitated through the interaction between instructors and students (Decristan et al., 2020), in our case instructors' behavior and their interactions with pre-service teachers. Two perspectives guide the understanding of INQ in relation to competence development: generic INQ focuses on general aspects of instruction necessary across all subjects, whereas content-specific INQ refers to factors needed for instruction in a specific subject and its unique content, pedagogical approaches and learning goals. Taking into account both perspectives separately, studies have found similar results: INQ dimensions from both perspectives predict how pre-service teachers develop in education (Blömeke & Olsen, 2019; Rindermann, 2023). Addressing the importance of both perspectives, Praetorius and Gräsel (2021), argue that they need to be considered together in order to better understand INQ and its synergistic effects on competence development.

#### 2.2.1. Generic instructional quality

Firstly, we will describe generic INQ, which focusses on universal principles of instruction and learning that apply across all subjects and educational levels. Various frameworks from K-12 address generic INQ (e.g., TBD: Klieme et al., 2001; Classroom Assessment Scoring System: Pianta et al., 2008; Framework for Teaching: Danielson et al., 2024). Regardless which framework is chosen, they may vary in terminology and emphasis, but the main idea of effective instruction remains mostly consistent (Charalambous & Praetorius, 2018; Praetorius et al., 2018).

The TBD framework defines INQ through three basic dimensions: classroom management, student support and cognitive activation (Klieme et al., 2001; Praetorius et al., 2018). Transferring the three basic dimensions into higher education context, classroom management refers to the organizational support of the teaching and learning process, for example clear time management and prevention of typical disturbances such as technical delays (Kunter et al., 2007). Student support refers to a supportive learning climate through, for example, positive relationships or positive attitudes towards mistakes (Fauth et al., 2019). Cognitive activation seeks to promote pre-service teachers' cognitive engagement with the content resulting in, for example, linking new to existing knowledge or applying concepts to authentic classroom scenarios (Fauth et al., 2019).

There are different approaches for investigating the effectiveness of generic INQ dimensions, i.e., variable-centered and person-centered approaches. While variable-centered approaches focus on the relation between individual variables, person-centered approaches examine patterns of co-occurring variables. Previous research using a variable-centered approach did show that certain aspects of INQ, such as cognitive activation, are positive predictors of students' cognitive development (Klieme et al., 2001; Praetorius et al., 2018), while student support is more closely linked to motivational and affective outcomes (Gebre et al., 2025; Jansen et al., 2022). Although these studies were conducted in K-12 contexts, the underlying mechanisms of INQ are suggested to apply to higher education and thus teacher education (Rindermann, 2023; Rubach et al., 2025). There are also studies which indirectly address the impact of generic INQ dimensions on TPACK development referring to the importance of challenging tasks and questions, exploring and activating prior knowledge and co-constructive learning (Killi et al., 2016; Qasem & Viswanathappa, 2016). For example, by incorporating generic INQ dimensions into a TPACK-informed intervention, Meletiou-Mavrotheris and Prodromou (2016) found that pre-service teachers' TPACK increased in settings were practice regarding classroom management, student support and cognitive activation were used, highlighting the effectiveness of generic INQ dimensions to foster TPACK.

While variable-centered studies have provided valuable insights into individual INQ dimensions, they have largely overlooked whether there are thresholds or levels of combined use of various INQ dimensions (i.e., orchestration), which we argue is necessary for fostering pre-service teachers' TPACK (Hirsch & Rubach, 2024). Such results are currently missing in teacher education. Holzberger and colleagues (2019) used a person-centered approach and found three different INQ profiles (high, medium, low) among K-12 math teachers. Results show that in-service teachers in the high instruction profile significantly positively predict students' achievement and emotional development. Interestingly, students taught by in-service teachers in the low and medium instruction profile showed no differences in their achievement. Furthermore, low INQ was associated with less enjoyment of students compared to students taught by in-service teachers in the medium instruction profile. These results suggest that higher levels of generic INQ are likely associated with a positive development of students' achievement in class. Transferring these results to our research focus, we assume that higher generic INQ leads to a positive development of pre-service teachers' TPACK.

Applying such person-centered methods in teacher education could provide insights into how INQ are implemented in classes, though, offer a more holistic way of understanding learning experiences. Generic INQ dimensions are theoretically considered to provide a basis for a high-quality learning environment and support the effective delivery of content-specific INQ dimensions. For example, a harmonious and time effective learning environment supports the delivery of content and enhances the application of content-specific INQ dimensions. Building on the theoretical assumption that generic INQ is the foundation of high-quality instruction, it can be assumed that these three dimensions underpin the development of TPACK, even though empirical evidence is limited.

#### 2.2.2. Content-specific instructional quality

Secondly, content-specific INQ refers to the effectiveness of instruction particularly related to a subject and content domain and thus acknowledges the unique characteristics of each subject (Charalambous & Praetorius, 2018; Praetorius & Gräsel, 2021).

In this study, we refer to content-specific INQ to support the development of pre-service teachers' TPACK. Hirsch and Rubach (2024) provided content-specific INQ dimensions to support pre-service teachers' TPACK development based on the SQD-model by Tondeur and colleagues (2012). Hereby they consider different practices and stakeholders important in teacher education, e.g., peers, instructors, in-service teachers and students. The provided dimensions are (1) role models, (2) empowerment, (3) interaction with teachers, (4) interaction with students and (5) feedback. This structure differs from the original SQD-model (Tondeur et al., 2012) and was identified in later work by Hirsch and Rubach (2024) using exploratory and confirmatory factor analyses. Hirsch and Rubach (2024) indicated a five-factor structure instead of the theoretically proposed six-factor structure. While the original dimensions *role model* and *feedback* remained unchanged, the new dimension *empowerment* represents an aggregated factor composed of the original SQD dimensions *reflection*, *collaboration*, *authentic experiences*, and *instructional design*. The factors *interaction with teachers* and *interaction with students* are newly composed factors. The first dimension refers to the importance of observing *role models* in ICT use (Howard et al., 2021). The second dimension, *empowerment*, combines the original factors of collaboration, authentic experiences, and instructional design, highlighting the empowerment of pre-service teachers in university classes. Whereas *interaction with teachers* and with *students* is related to the discussion and collaboration with in-service teachers and students regarding the use of ICT in classrooms (Hirsch & Rubach, 2024). Finally, *feedback* provides pre-service teachers with information about mistakes and guidance on how to improve their own ICT use for future professional tasks.

Similar to generic INQ, several cross-sectional (Baran et al., 2019; Buchner & Hofmann, 2022; Knezek et al., 2024; Rubach & Lazarides, 2021) and longitudinal studies (Christensen & Trevisan, 2023; Hsu & Lin, 2020; Lachner et al., 2021) have used a variable-centered approach to understand the impact of INQ on pre-service teachers' TPACK. Hereby, either single dimensions (Hsu & Lin, 2020) or all SQD dimensions have been investigated as predictors (Hirsch & Rubach, 2024). For example, role models positively influence pre-service teachers' TPACK (Tondeur et al., 2020; Wang et al., 2018). Focusing on the effectiveness of all SQD dimensions, Lachner and colleagues (2021) indicated that pre-service teachers demonstrated a more positive development of TPACK in learning environments where all SQD dimensions were implemented, compared to environments without the use of the SQD dimensions (Buchner & Hofmann, 2022). More recent findings highlighted that no single but rather the orchestration of all dimensions within learning environments foster pre-service teachers' TPACK (Hirsch & Rubach, 2024).

#### 2.2.3. The interplay between generic and content-specific instructional quality

Focusing exclusively on either the generic or content-specific INQ perspective presents a challenge overlooking how both interact to foster competence development. As said before, considering only one perspective may provide only a partial view of the complex process of effective digital education. An integrated approach may provide a more holistic perspective on teaching-learning processes and thus facilitate a chance to understand the impact on pre-service teachers' academic growth in context of TPACK development in more detail (e.g., Praetorius & Gräsel, 2021; Senden et al., 2022).

While the relevance of both perspectives is acknowledged, one challenge lies in the fact that they overlap in their components, making it somehow challenging to draw clear distinctions. Some scholars argue that INQ is initially generic and only become content-specific through adaptation to subject contexts (Dreher & Leuders, 2021; Heinitz et al., 2022) and retain cross-subject transferable (Wiprächtiger-Geppert et al., 2021). Others emphasize the coexistence of both perspectives within certain practices, describing them as “hybrids” (Praetorius & Charalambous, 2018). For instance, cognitive activation as one generic dimension (TBD; Klieme et al., 2001) is often linked to content-specific INQ as it promotes engagement with subject matter (Praetorius & Charalambous, 2018; Schlesinger & Jentsch, 2016). This implies the distinction is less about their inherent nature and more about their level of abstraction (Heinitz et al., 2022). As a result, several comparative frameworks (Blazar et al., 2017; Charalambous & Kyriakides, 2017; Praetorius & Charalambous, 2018) and new hybrid models (e.g., MAIN-TEACH model: Praetorius et al., 2023; Measures of Effective Teaching: Kane & Staiger, 2012; UTeach Observation Protocol: Walkington & Marder, 2015) have emerged to picture how different INQ perspectives align. Although hybrid models incorporating these concepts have been described in literature, they have not yet been empirically examined. These gaps underscore the importance of investigating which learning experiences pre-service teachers encounter in their seminars and how the combination of different experiences (i.e., generic and content-specific INQ) impact their TPACK development.

### 2.3. The present study

We aim to investigate the extent to which pre-service teachers' TPACK depend on INQ dimensions. Praetorius and Gräsel (2021) point to the necessity of combining generic and content-specific INQ perspectives to fully capture INQ and its impact on competence development. Applying this perspective, we use a person-centered approach to examine pre-service teachers' learning experiences with various INQ dimensions. We focus on following research questions:

***RQ1***. *How can pre-service teachers' learning experiences with generic and content-specific INQ dimensions be classified into distinct profiles,* *considering both the occurrence and satisfaction of these dimensions?*

While this study is exploratory in nature, we hypothesize the emergence of multiple profiles, building on the findings of Holzberger and colleagues (2019), who found three distinct INQ profiles. From a methodological perspective, separating occurrence and satisfaction in the analysis provides more nuanced insights, i.e., occurrence of INQ dimensions does not automatically imply high satisfaction, and vice versa, revealing dynamics in the implementation of INQ dimensions.

In addition, based on our prior findings (Hirsch & Rubach, 2024), we hypothesize that pre-service teachers' TPACK develops positively if the orchestration of all generic and content-specific INQ dimensions have occurred and are perceived as satisfactory from pre-service teachers. This expectation is further guided by the findings of Holzberger and colleagues (2019), who reported that K-12 teachers' high-quality INQ profile is positively related with students' development of achievement, suggesting that similar processes of INQ and learning outcome may also be present in higher education, despite different contexts. To explore this, we investigate how pre-service teachers' TPACK differ across profiles with the following research question:

***RQ2.*** *How do these INQ profiles, defined by occurrence and satisfaction ratings, relate to pre-service teachers' TPACK development?*

## 3. Methodology

### 3.1. Study design and sample

To address our research questions, we analyzed data from the preregistered *SkillfulTeacher2.0* project (Rubach, 2024b) conducted at the University of Rostock in Germany. One goal of the project was to explore how content, instructional methods, and INQ within university seminars influence the development of digital competence of pre-service teachers. The study surveyed overall 904 pre-service teachers in two cohorts (summer term 2023: n = 720; winter term 2023/2024: n = 184) using a convenience sampling approach. Instructors offering seminars with a focus on digital education, identified based on the course catalogue and the corresponding course descriptions, were approached and asked to participate. In case of participation, they were also asked to choose one similar seminar without a focus on digital education serving as their control group. The aim was to capture a broad range of subject domains in teacher education. Data from three time points (beginning, midpoint and end of courses during the semester; Supplemental Material, Part 1) were collected using paper-and-pencil and online questionnaires. Pre-service teachers were surveyed in one lecture and 40 seminars, where eighteen seminars functioned as control groups without a digital education focus. The participation was voluntary and approved by institutional review board (IRB) requirements.

For the aim of this paper, a subsample[2] was used based on the following restrictions: we only considered pre-service teachers who answered items related to the SQD-model and TBD framework as well as TPACK items from the first and the last survey as this had the mandatory items included. Only seminars were considered ensuring a constant teaching context, as they typically involve a fixed group of university students and one instructor who meet regularly (e.g., weekly) to work on a specific topic. Seminars with fewer than five participants were excluded to ensure sufficient heterogeneity in the ratings within these courses. We also excluded cases with double enrollment in multiple seminars to maintain independence of observations. As a result of these restrictions, the final sample included data from 248 pre-service teachers (male = 32 %; $\bar{x}_{age} = 23.6$; SD = 3.09; $\bar{x}_{semester} = 7.2$; 34 % secondary school (high academic track), control group n = 85) from 24 seminars, who were enrolled in various K-12 teacher education programs and various subjects[3] (Supplemental Material, Part 2).

### 3.2. Instruments

All items and their internal consistency are presented in the Supplemental Material, Part 3.

***Instructional Quality (i.e., TBD & SQD).*** Applying to both generic and content-specific INQ, we captured pre-service teachers' perceptions INQ according to (a) occurrence of and (b) satisfaction with their experiences, guided by the person-environment fit approach (Eccles et al., 1993; Rubach et al., 2022; Tinto, 1993). This separation of observation of INQ dimensions is in line with Murray (2007), who distinguishes between low-inference indicators, such as objective observable behaviors of the instructor (i.e., occurrence of INQ dimensions) and high-inference, which involves subjective judgements and interpretation (i.e., satisfaction with INQ dimensions). At the end of the semester, pre-service teachers responded to a total of 28 INQ items (Supplemental Material, Part 3; Rubach et al., 2022; Tondeur et al., 2017a) on a Likert scale ranging from *0 = did not occur, 1 = not satisfied at all* to *7 = completely satisfied*. Thus, occurrence and satisfaction items were measured with the same scale based on pre-service teachers' perceptions. For the analysis, however, the original scales were recoded: for occurrence, responses were recoded into a binary variable (0 = did not occur and 1–7 = recoded as 1, indicating occurrence). Satisfaction was analyzed only for cases in which the item was reported to have occurred (i.e., responses 1–7). Consequently, each item was represented by two values: a binary occurrence indicator and a corresponding satisfaction rating.

In line with the TBD framework, generic INQ was conceptualized through three dimensions with ten items: classroom management (three items), student support (four items) and cognitive activation (three items; Supplemental Material, Part 3). The reliability of the scales was good (.68 ≤ Ω ≤ .87).

To assess content-specific INQ, we used the existing instrument on various content-related INQ dimensions that are guided by the SQD framework (Hirsch & Rubach, 2024; Supplemental Material, Part 3). The scale includes five factors: role model and feedback (each measured with three items), empowerment (six items), interaction with teachers (four items) and interaction with students (two items). The reliability of the scales was good (.88 ≤ Ω ≤ .94).

***TPACK.*** To assess the development of pre-service teachers' self-perceived TPACK as one aspect of competence, four items from the TPCK.xs subscale from Schmid and colleagues (2020) were used (Supplemental Material, Part 3). Pre-service teachers were asked in the beginning and at the end of the semester about their self-perceived TPACK, using a 7-point Likert scale ranging from *1 = strongly disagree* to *7 = strongly agree*. The scale demonstrated high internal consistency (Ω = .92).

### 3.3. Statistical analyses

All analyses were computed using *SPSS* version 29 and M*plus* 8.11 (Muthén & Muthén, 1988-2017). As we were interested in the relationships between explored INQ-profiles and pre-service teachers' TPACK development, we conducted two analyses steps which are described in the following. Detailed syntax files of all analyses are provided in the Supplemental Material, Parts 4-6.

To answer RQ1, we conducted a two-step latent profile analysis to investigate the optimal number of latent profiles that we generated with pre-service teachers' perception of (a) the occurrence of and (b) their

[2] We used almost the same subsample in a publication from 2024 (Hirsch & Rubach). Minor differences in sample size resulted from the inclusion of items regarding generic INQ.

[3] For more information see Supplemental Material, Part 2. More than one subject could have been chosen since teacher education in Germany involves studying several subjects simultaneously.

satisfaction with generic and content-specific INQ dimensions. We chose this two-step approach because occurrence represents a low-inference measure of perceived presence of INQ dimensions during seminars, whereas satisfaction represents a high-inference, subjective evaluation.

As preliminary analysis, we examined the correlations between generic and content-specific dimensions to avoid multicollinearity by using the variance inflation factor (VIF; Leaper & Starr, 2018). There was no identification of multicollinearity, as all analyses presented a VIF above .1 and below 10 (1.88-3.84). Furthermore, as pre-service teachers were nested within seminars, we analyzed the intraclass correlation coefficient type 1 (ICC1), i.e., the extent to which variance was attributable to pre-service teachers' seminar membership (Lüdtke et al., 2011). Less than five percent of the variance of TPACK was attributable to seminar membership, while for generic INQ it ranged from 29 % to 30 % and for content-specific INQ from 33 % to 59 %.

Models with one to seven profiles were tested using the robust maximum likelihood estimation (Muthén & Muthén, 2012): first, based on the occurrence of INQ dimensions, and second, based on pre-service teachers' satisfaction with these occurred dimensions. Notably, only pre-service teachers who had experienced the INQ dimensions in the first step were included in the second step of analysis. According to Rahden and colleagues (2025), there are six different modeling approaches for latent profile analysis which consider different variance-covariance matrices (VCM). We conducted all six approaches and used the method which fits the data best. To interpret the various modeling approaches, we compared different fit indices based on Rahden and colleagues (2025) guidance for LPA interpretation and analyzed the following fit indices: Log-Likelihood value, Bayesian Information Criterion (BIC), Vuong-Lo-Mendell-Rubin likelihood ratio test (VLMR), the Bootstrapped likelihood ratio test (BLRT), group sizes of the profiles, and entropy values. In addition to these fit indices, it is essential to consider theoretical aspects when determining the most appropriate profile solution (Spurk et al., 2020). If an additional profile contributes new and relevant information, it should be retained. Furthermore, we compared the mean level differences across all INQ scales using one-way ANOVAs followed by post hoc tests (Tukey) in *SPSS* to understand differences in the profile composition.

The final step (RQ2) was a multi-group latent change model to test if the profiles differ according to their TPACK development. The latent change model (Hu & Bentler, 1999) has already been calculated and reported previously (Hirsch & Rubach, 2024) and is now being reused to analyze profile-specific variations. Due to differences in sample sizes, we tested whether the missing data for the TPACK construct was completely at random (MCAR test). The results indicated that the MCAR assumption could not be rejected ($\chi^2(2) = 5.80$, $p = .06$). Furthermore, to confirm that the construct TPACK is assessed the same way across the two time points, measurement of invariance (MI) was tested by the criteria of Chen (2007). Partial scalar MI was confirmed for TPACK (Supplemental Material, Part 7). To answer RQ2 we conducted multi-group latent change models for the occurrence profiles (O1-O4) and for the satisfaction profiles (S1-S2). To ensure the robustness of our findings, we estimated whether the inclusion of potential covariates (i.e., gender, semester of study) would affect the results. Subsequently, we used the Wald chi-square test of parameter equalities (Kodde & Palm, 1986) and tested whether the slopes for the TPACK development differ significantly across profiles.

## 4. Results

### *4.1. Correlations between instructional quality dimensions and TPACK*

Results of correlations between the generic and content-specific INQ dimensions and TPACK are demonstrated in Tables 1 and 2.

**Table 1**
Correlation analysis of instructional quality dimensions.

| Factors | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1. CM | 1 | **.67** | **.81** | **.51** | **.44** | **.38** | .07 | **.43** |
| 2. CC | **.50** | 1 | **.71** | **.52** | **.41** | **.33** | **.21** | **.45** |
| 3. CA | **.46** | **.60** | 1 | **.61** | **.52** | **.40** | .16 | **.45** |
| 4. RoMo | **.18** | **.28** | **.18** | 1 | **.73** | **.66** | **.45** | **.59** |
| 5. Emp | **.14** | **.23** | **.14** | **.71** | 1 | **.73** | **.61** | **.69** |
| 6. IntT | **.27** | **.24** | .08 | **.49** | **.64** | 1 | **.67** | **.63** |
| 7. IntS | .11 | **.21** | .05 | **.36** | **.53** | **.69** | 1 | **.55** |
| 8. Feedb | **.20** | **.28** | **.16** | **.55** | **.73** | **.65** | **.62** | 1 |

*Note.* The correlations reported are estimated on the basis of the mean scale scores. Correlations below the diagonal represent low-inference (e.g., occurrence of INQ dimensions) ratings, whereas correlations above the diagonal represent high-inference (e.g., satisfaction with INQ dimensions) ratings. Bold highlighted values are significant ($p \leq .05$). CM = Classroom Management, CC = Student Support, CA = Cognitive Activation, RoMo = Role Model, Emp = Empowerment, IntT = Interaction with Teachers, IntS = Interaction with Students, Feedb = Feedback.

**Table 2**
Correlation Analysis of Instructional Quality Dimensions with TPACK over time.

| Factors | $TPACK_{t1}$ | $TPACK_{t2}$ |
|---|---|---|
| CM1 | .08 | **.15** |
| CM2 | −.03 | **.19** |
| CC1 | −.06 | **.16** |
| CC2 | .00 | **.21** |
| CA1 | .05 | .09 |
| CA2 | −.02 | **.23** |
| RoMo1 | .13 | **.27** |
| RoMo2 | −.08 | **.24** |
| Emp1 | .03 | **.28** |
| Emp2 | .05 | **.39** |
| IntT1 | .10 | **.22** |
| IntT2 | .02 | **.29** |
| IntS1 | −.03 | **.15** |
| IntS2 | −.03 | .16 |
| Feedb1 | .07 | **.32** |
| Feedb2 | −.07 | **.26** |

*Note.* Latent variable means are used for the analysis. Bold highlighted values are significant ($p \leq .05$). CM = Classroom Management, CC = Student Support, CA = Cognitive Activation, RoMo = Role Model, Emp = Empowerment, IntT = Interaction with Teachers, IntS = Interaction with Students, Feedb = Feedback, factor1 = occurrence, factor2 = satisfaction.

The significant correlations vary between $r = .14$ and $r = .81$ for generic and content-specific INQ dimensions. This result indicates varying relationships, where some dimensions show weak positive or even negative associations, while others are strongly positively related. Notably, content-specific *role models* on the INQ scale were significantly positively correlated with all three generic INQ dimensions in both occurrence and satisfaction contexts. The correlations were consistently higher in the satisfaction context, i.e., *classroom management* ($r = .51$, $p \leq .001$), *student support* ($r = .52$, $p \leq .001$), and *cognitive activation* ($r = .61$, $p \leq .001$). Another result we want to highlight is the strong positive correlation between the occurrence of *empowerment* and *feedback*, and between satisfaction with *empowerment* and the satisfaction with *interaction with teachers* (both $r = .73$, $p \leq .001$). Furthermore, we found significant correlations between most of all INQ dimensions and TPACK at the end of the semester (Table 2), which points out that the more satisfied pre-service teachers are with INQ dimensions, the higher they report their TPACK. There is one exception: pre-service teachers' self-perceived TPACK is independent of *interaction with students*.

### 4.2. Results for the occurrence of instructional quality dimensions

We performed latent profile analyses with varying numbers of profiles and six different VCMs (Approach A-F; Table 3, Rahden et al., 2025). In the following, we first describe results on the occurrence profiles (RQ1), with profiles labelled *O* for occurrence followed by the profile number. No variation in occurrence was found for generic INQ; thus, the analysis of occurrence profiles is solely based on content-specific INQ dimensions. Second, results are described for the TPACK development across profiles (RQ2).

#### 4.2.1. Results of the latent profile analysis (RQ1)

For RQ1, we identified fitting profile solutions within two latent profile approaches: a four-profile solution for the *VCM specification A* [profile-invariant variances, diagonal] and a three-profile solution for the *VCM specification C* [profile-invariant variances, invariant covariances] (Table 3). Comparing both profile solutions, the statistical indicators suggested that either option could be considered adequate: both solutions yielded significant VLMRT and BLRT, entropy values were above .80, and size of the smallest group was over five percent of the total subsample. However, the four-profile solution in *VCM specification A* showed a lower BIC value, which is one indicator of a better model fit compared to the other profile solution. In addition to these statistical criteria, theoretical considerations played a decisive role in selecting the profile solution. Following Spurk and colleagues (2020), additional profiles should be retained when they offer meaningful and conceptually relevant distinctions. The three-profile solution in *VCM specification C* revealed one high, one low and a moderate profile. The four-profile solution in *VCM specification A* revealed a high and a low profile and also two distinct mixed profiles. These two mixed profiles provided a distinct perception on class design in teacher education. Therefore, despite both solutions being statistically acceptable, the four-profile solution was chosen based on content-related criteria.

Using the profile solution from the *VCM specification A* (Fig. 1), pre-service teachers in profile O1 (n = 38) reported almost no occurrence of all SQD dimensions, except some experiences of *role models* within their seminars. Pre-service teachers in profile O4 (n = 119) reported the occurrence of all SQD dimensions. Thus, profile O1 is named *Low Occurrence* and profile O4 is named *High Occurrence*. Profile O2 (n = 34) and profile O3 (n = 57) contained pre-service teachers with mixed patterns: Pre-service teachers in profile O2 reported high occurrence of *role models* and medium occurrence of *empowerment*, but low occurrence of *feedback* and *interaction with in-service teachers* and *interaction with students* in the seminars. Thus, profile O2 is named *Low Interaction.* Pre-service teachers in profile O3 reported high occurrence of *role models*,

**Table 3**
Overview of model fit indices of all latent profile analysis.

| # Profiles | #Par | LL | LL Replicated? | AIC | BIC | SABIC | Entropy | VLMRT | aVLMRT | BLRT |
|---|---|---|---|---|---|---|---|---|---|---|
| Step 1: Low inference (occurrence of content-specific INQ dimensions, 5 scales) | | | | | | | | | | |
| Variant A: Profile-invariant variances, diagonal | | | | | | | | | | |
| 2 | 16 | −240.414 | Yes | 512.827 | 569.042 | 518.322 | .986 | <.001 | <.001 | <.001 |
| 3 | 22 | −78.943 | Yes | 201.885 | 279.181 | 209.440 | .955 | .001 | .001 | <.001 |
| **4** | **28** | **48.163** | **Yes** | **−40.325** | **58.051** | **−30.710** | **.974** | **.011** | **.012** | **<.001** |
| 5 | 34 | 119.267 | Yes | −170.533 | −51.077 | −158.857 | .981 | .139 | .145 | <.001 |
| 6 | 40 | 166.936 | Yes | −253.873 | −113.336 | −240.137 | .981 | .359 | .370 | <.001 |
| 7 | 46 | 252.738 | No | −413.475 | −251.858 | −397.679 | .993 | .649 | .656 | <.001 |
| Variant B: Profile-varying variances, diagonal | | | | | | | | | | |
| 2 | 21 | −67.019 | Yes | 176.039 | 249.821 | 183.250 | .993 | .386 | .392 | <.001 |
| 3 | 32 | −622.858 | No | 1.309.717 | 1.422.146 | 1.320.706 | 1.00 | .614 | .608 | 1.00 |
| 4 | / | / | No | / | / | / | / | / | / | / |
| 5 | / | / | No | / | / | / | / | / | / | / |
| 6 | / | / | No | / | / | / | / | / | / | / |
| 7 | / | / | No | / | / | / | / | / | / | / |
| Variant C: Profile-invariant variances, invariant covariances | | | | | | | | | | |
| 2 | 26 | −117.705 | Yes | 287.410 | 378.759 | 296.339 | 1.00 | <.001 | <.001 | <.001 |
| 3 | 32 | −3.607 | Yes | 71.214 | 183.644 | 82.203 | .966 | .006 | .007 | <.001 |
| 4 | 38 | 86.578 | No | −97.156 | 36.355 | −84.106 | .976 | .056 | .061 | <.001 |
| 5 | 44 | 156.030 | No | −224.059 | −69.468 | −208.949 | .992 | .224 | .231 | <.001 |
| 6 | 50 | 183.411 | Yes | −266.821 | −91.150 | −249.651 | .973 | .411 | .423 | <.001 |
| 7 | 56 | 252.628 | No | −393.256 | −196.504 | −374.026 | .986 | .148 | .154 | <.001 |
| Variant D: Profile-invariant variances, varying covariances | | | | | | | | | | |
| 2 | 36 | −88.339 | Yes | 248.679 | 375.162 | 261.041 | .969 | .280 | .284 | <.001 |
| 3 | 52 | −.314 | No | 104.628 | 287.326 | 122.485 | .978 | .263 | .263 | 1.00 |
| 4 | 68 | 110.313 | No | −84.625 | 154.288 | −61.274 | .984 | .243 | .246 | <.001 |
| 5 | 84 | 89.278 | No | −10.556 | 284.572 | 18.290 | .991 | .240 | .240 | <.001 |
| 6 | 100 | −45.898 | No | 291.796 | 643.139 | 326.137 | .987 | .240 | .240 | 1.00 |
| 7 | 116 | −28.874 | No | 289.747 | 697.305 | 329.582 | .986 | .240 | .240 | .512 |
| Variant E: Profile-varying variances, invariant covariances | | | | | | | | | | |
| 2 | 31 | 2.565 | No | 56.869 | 165.786 | 67.515 | .982 | .631 | .637 | <.001 |
| 3 | 42 | −5.508 | No | 95.016 | 242.580 | 109.439 | .990 | .611 | .611 | 1.00 |
| 4 | / | / | No | / | / | / | / | / | / | / |
| 5 | / | / | No | / | / | / | / | / | / | / |
| 6 | / | / | No | / | / | / | / | / | / | / |
| 7 | / | / | No | / | / | / | / | / | / | / |
| Variant F: Profile-varying variances, varying covariances | | | | | | | | | | |
| 2 | 41 | 34.931 | Yes | 12.138 | 156.189 | 26.218 | .986 | .421 | .425 | <.001 |
| 3 | / | / | No | / | / | / | / | / | / | / |
| 4 | / | / | No | / | / | / | / | / | / | / |
| 5 | 104 | 273.985 | No | −339.969 | 25.427 | −304.255 | .994 | .697 | .697 | <.001 |
| 6 | / | / | No | / | / | / | / | / | / | / |
| 7 | / | / | No | / | / | / | / | / | / | / |

(*continued on next page*)

**Table 3** (*continued*)

| # Profiles | #Par | LL | LL Replicated? | AIC | BIC | SABIC | Entropy | VLMRT | aVLMRT | BLRT |
|---|---|---|---|---|---|---|---|---|---|---|
| Step 2: High inference (satisfaction with generic and content-specific INQ dimensions, 8 scales) | | | | | | | | | | |
| Variant A: Profile-invariant variances, diagonal | | | | | | | | | | |
| 2 | 25 | −2.223.554 | Yes | 4.497.108 | 4.580.785 | 4.501.571 | .919 | .001 | .001 | <.001 |
| 3 | 34 | −2.131.722 | Yes | 4.331.444 | 4.445.246 | 4.337.515 | .937 | .352 | .359 | <.001 |
| 4 | 43 | −2.054.335 | Yes | 4.194.670 | 4.338.596 | 4.202.347 | .898 | .412 | .416 | <.001 |
| 5 | 52 | −2.003.969 | Yes | 4.111.939 | 4.285.988 | 4.121.222 | .885 | .120 | .123 | <.001 |
| 6 | 61 | −1.964.706 | Yes | 4.051.412 | 4.255.586 | 4.062.303 | .873 | .535 | .542 | <.001 |
| 7 | 70 | −1.931.531 | Yes | 4.003.062 | 4.237.360 | 4.015.559 | .896 | .417 | .421 | <.001 |
| Variant B: Profile-varying variances, diagonal | | | | | | | | | | |
| 2 | 33 | −2.084.806 | Yes | 4.235.611 | 4.346.066 | 4.241.503 | .922 | <.001 | <.001 | <.001 |
| 3 | 50 | −2.010.795 | Yes | 4.121.591 | 4.288.946 | 4.130.517 | .914 | .339 | .343 | <.001 |
| 4 | 67 | −1.798.375 | No | 3.730.751 | 3.955.007 | 3.742.712 | .942 | .232 | .236 | <.001 |
| 5 | 84 | −2.010.795 | No | 4.189.591 | 4.470.748 | 4.204.587 | .941 | .240 | .240 | 1.00 |
| 6 | 101 | −1.680.705 | No | 3.563.411 | 3.901.469 | 3.581.442 | .935 | .231 | .233 | <.001 |
| 7 | / | / | No | / | / | / | / | / | / | / |
| Variant C: Profile-invariant variances, invariant covariances | | | | | | | | | | |
| 2 | 53 | −1.957.254 | Yes | 4.020.508 | 4.197.905 | 4.029.971 | .886 | .003 | .004 | <.001 |
| 3 | 62 | −1.917.413 | Yes | 3.958.827 | 4.166.347 | 3.969.896 | .923 | .066 | .071 | <.001 |
| 4 | 71 | −1.877.359 | Yes | 3.896.718 | 4.134.363 | 3.909.394 | .921 | .421 | .430 | <.001 |
| 5 | 80 | −1.850.279 | Yes | 3.860.558 | 4.128.327 | 3.874.841 | .931 | .600 | .604 | <.001 |
| 6 | 89 | −1.826.615 | No | 3.831.230 | 4.129.123 | 3.847.120 | .922 | .354 | .355 | .002 |
| 7 | 98 | −1.808.673 | No | 3.813.345 | 4.141.362 | 3.830.842 | .938 | .714 | .715 | .028 |
| Variant D: Profile-invariant variances, varying covariances | | | | | | | | | | |
| 2 | 81 | −1.850.724 | Yes | 3.863.447 | 4.134.563 | 3.877.908 | .910 | .005 | .005 | <.001 |
| 3 | 118 | −1.759.887 | No | 3.755.774 | 4.150.732 | 3.776.841 | .926 | .682 | .683 | <.001 |
| 4 | 155 | −1.709.056 | No | 3.728.113 | 4.246.914 | 4.246.914 | .879 | .241 | .241 | .184 |
| 5 | 192 | −1.672.682 | No | 3.729.364 | 4.372.008 | 3.763.642 | .880 | <.001 | <.001 | 1.00 |
| 6 | 229 | −1.608.084 | No | 3.674.168 | 4.440.656 | 3.715.052 | .929 | .763 | .763 | .708 |
| 7 | 266 | −1.657.685 | No | 3.847.369 | 4.737.700 | 3.894.859 | .948 | .240 | .240 | 1.00 |
| Variant E: Profile-varying variances, invariant covariances | | | | | | | | | | |
| 2 | 61 | −1.857.389 | Yes | 3.836.779 | 4.040.953 | 3.847.669 | .845 | .493 | .496 | <.001 |
| 3 | 78 | −1.747.172 | Yes | 3.650.345 | 3.911.419 | 3.664.270 | .883 | .028 | .029 | <.001 |
| 4 | 95 | −1.689.053 | No | 3.568.106 | 3.886.081 | 3.585.067 | .894 | .337 | .341 | <.001 |
| 5 | 112 | −1.670.008 | No | 3.564.016 | 3.938.892 | 3.584.012 | .892 | / | / | / |
| 6 | 129 | −1.670.510 | No | 3.599.019 | 4.030.796 | 3.622.050 | .901 | .394 | .394 | 1.00 |
| 7 | 146 | −1.666.062 | No | 3.624.125 | 4.112.803 | 3.650.191 | .907 | / | / | / |
| Variant F: Profile-varying variances, varying covariances | | | | | | | | | | |
| **2** | **89** | **−1.785.918** | **Yes** | **3.749.835** | **4.047.728** | **3.765.725** | **.938** | **<.001** | **<.001** | **<.001** |
| 3 | 134 | −1.665.116 | No | 3.598.233 | 4.046.745 | 3.622.156 | .896 | .453 | .455 | <.001 |
| 4 | 179 | −1.594.246 | No | 3.546.492 | 4.145.624 | 3.578.449 | .911 | .475 | .477 | <.001 |
| 5 | 224 | −1.527.450 | No | 3.502.900 | 4.252.652 | 3.542.891 | .924 | .788 | .788 | .070 |
| 6 | 269 | −1.655.525 | No | 3.849.051 | 4.749.423 | 3.897.076 | .910 | .240 | .240 | 1.00 |
| 7 | 314 | −1.497.307 | No | 3.622.614 | 4.673.605 | 3.678.673 | .934 | .753 | .753 | .231 |

*Note*. Boldface font indicates the selected models; 1. Step N = 248/2. Step N = 210; #Par = Number of estimated parameters; LL = Log-Likelihood; LL Replicated = Log-Likelihood replicated?; BIC = Bayesian information criterion; SABIC = Sample-size adjusted Bayesian information criterion; VLMR = Vuong-Lo-Mendell-Rubin Test; aVLMRT = Adjusted Vuong-Lo-Mendell-Rubin likelihood ratio test; BLRT = Bootstrap-Likelihood-Ratio Test. / = model parameters could not be estimated.

*empowerment* and *feedback* but little *interaction with in-service teachers* and no occurrence of *interaction with students* and is therefore named *Role Model and Empowerment Focused.*

### 4.2.2. *Results of the TPACK development across identified profiles (RQ2)*

To answer RQ2, we conducted multi-group latent change models. Results indicated an acceptable overall model fit to the data ($\chi^2$ (74) = 153.18, $p \leq .001$; CFI = .96; TLI = .96; RMSEA = .09; SRMR = .10)[4] and no significant changes in pre-service teachers' TPACK development in almost all profiles, i.e., O1, O3 and O4 (Table 4 and Fig. 1). However, some non-significant but interesting trends were found that we want to point out: a negative TPACK trend in the *Low Occurrence* profile (O1; $ß_{\Delta TPACK}$ = - .39; 95 % CI [-.80; .02]; d = −.30, $p > .05$), and a positive TPACK trend in the *Role Model and Empowerment Focused* profile (O3; $ß_{\Delta TPACK}$ = .26; 95 % CI [-.08; .60]; d = .21, $p > .05$) and *High Occurrence* profile (O4; $ß_{\Delta TPACK}$ = .16; 95 % CI [-.09; .42]; d = .12, $p > .05$). Pre-service teachers grouped in the *Low Interaction* profile (i.e., O2) showed a statistically significant decrease in TPACK from the beginning to the end of the semester ($ß_{\Delta TPACK}$ = −.34, $p \leq .05$; 95 % CI [-.67; - .01]; d = −.35, $p \leq .05$). The Wald-tests indicated significant differences in the TPACK development across profiles, i.e., profiles O1 and O3 ($\chi^2$ (1) = 5.31, $p \leq .05$), profiles O1 and O4 ($\chi^2$ (1) = 3.87, $p \leq .05$), profiles O2 and O3 ($\chi^2$ (1) = 6.95, $p \leq .01$) and profiles O2 and O4 ($\chi^2$ (1) = 5.33, $p \leq .05$). In summary, pre-service teachers in these profiles have somewhat distinct patterns of INQ and also distinct TPACK developments.

Lastly, for robustness test we included covariates in the analyses (i.e., gender and semester of study[5]) which identified slightly different changes in TPACK development across profiles, i.e., indicating a minor influence of these covariates on TPACK development. However,

[4] Although RMSEA and the SRMR slightly exceeded conventional cut-offs, high CFI and TLI values indicate acceptable model fit, suggesting that the model adequately represents the latent change structure of TPACK across profiles (Supplemental Material, Part 8). Such deviations are not unusual in complex latent change models and may reflect sample size limitations. Clustering was examined as a robustness check in the latent change models, yielding identical results. Therefore, we report the results from the models without accounting for the nested data structure.

[5] Gender and semester of study have been chosen because of empirical studies who found that demographic characteristics can systematically influence self-assessed TPACK. For example, Gómez-Trigueros and Yáñez de Aldecoa, (2021) found that female teachers rated themselves lower in TPACK level than their male peers.

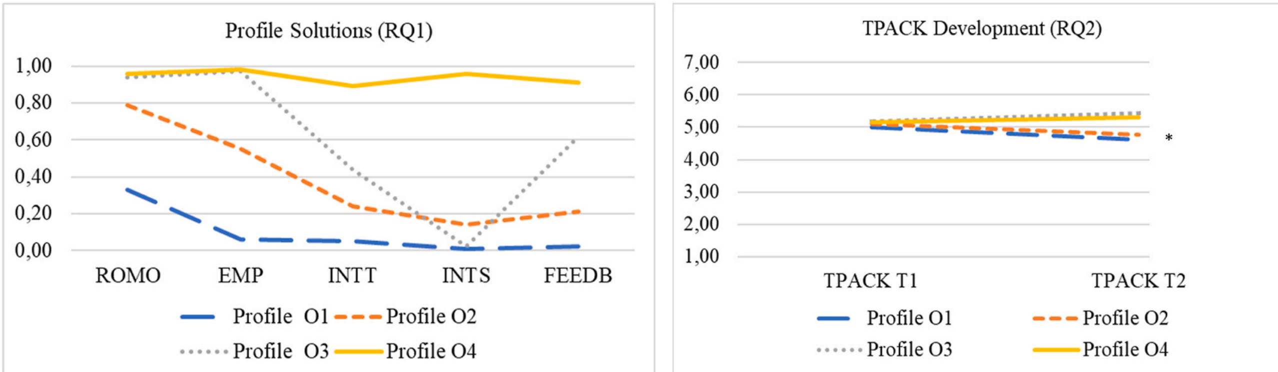


**Fig. 1.** *Four-Profile Solution for Occurrence of Instructional Quality Dimensions* (RQ1) and Profile-Based TPACK Development (RQ2)
*Note.* $p \le .05$ (*), $p \le .01$ (**). Profile O1 = low occurrence [n = 38]; Profile O2 = low interaction [n = 34]; Profile O3 = role model and empowerment focused [n = 57] and Profile O4 = high occurrence [n = 119].

**Table 4**
Step 1 (occurrence): Estimated means and longitudinal change in TPACK across profiles.

| Factors | Approach A: 4-Profile Solution | | | | | | |
|---|---|---|---|---|---|---|---|
| | Profile O1 | Profile O2 | Profile O3 | Profile O4 | F (df) | *p* | Interpretation |
| | *M (SE)* | *M (SE)* | *M (SE)* | *M (SE)* | | | |
| RoMo | .33 (.06) | .79 (.05) | .94 (.02) | .96 (.02) | 78.79 (3, 243) | <.001 | O1 < O2 < O3 = O4 |
| Emp | .06 (.02) | .55 (.03) | .97 (.01) | .98 (.01) | 1581.92 (3, 244) | <.001 | O1 < O2 < O3 = O4 |
| IntT | .05 (.02) | .24 (.05) | .44 (.06) | .89 (.03) | 106.10 (3, 243) | <.001 | O1 < O2 < O3 < O4 |
| IntS | .01 (.01) | .14 (.05) | .02 (.01) | .96 (.01) | 854.07 (3, 243) | <.001 | O1 = O3 < O2 < O4 |
| Feedb | .02 (.01) | .21 (.06) | .62 (.06) | .91 (.02) | 123.33 (3, 244) | <.001 | O1 < O2 < O3 < O4 |
| $TPACK_{t1}$ | 4.90 (.21) | 5.08 (.23) | 5.06 (.16) | 5.15 (.13) | | | |
| $TPACK_{t2}$ | 4.62 (.19) | 4.75 (.17) | 5.36 (.17) | 5.31 (.13) | | | |
| $ß\Delta_{TPACK}$ | −.28 | **−.33** | .30 | .16 | | | |

*Note.* N = 248. Profile O1 = low occurrence [n = 38]; Profile O2 = low interaction [n = 34]; Profile O3 = role model and empowerment focused [n = 57] and Profile O4 = high occurrence [n = 119]. Estimated means from a scale from 0 to 1 for content-specific instructional quality dimensions and 1-7 for TPACK. Bold highlighted values are significant ($p \le .05$). CM = Classroom Management, CC = Student Support, CA = Cognitive Activation, RoMo = Role Model, Emp = Empowerment, IntT = Interaction with Teachers, IntS = Interaction with Students, Feedb = Feedback, $TPACK_{t1}$ = TPACK first measurement point, $TPACK_{t2}$ = TPACK second measurement point, $ß\Delta_{TPACK}$ = Change of TPACK over time; F = test statistic for ANOVA; df = degrees of freedom; Interpretation = Profile comparisons indicate the relative order of mean values across profiles.

compared to analyses without covariance, no differences occurred in significance or direction of the TPACK development across profiles.

### 4.3. Results for the satisfaction with instructional quality dimensions

In the second step, we focused on satisfaction ratings and used a subsample consisting only of the pre-service teachers from the pro files in which INQ dimensions have occurred (profiles O2, O3 and O4; n = 210). Pre-service teachers in the profile with no occurrence in all INQ dimensions (n = 38) were excluded. In the following, we first describe results of the latent profile analysis for satisfaction with INQ dimensions, with profiles labelled *S* for satisfaction followed by the profile number, and second, results for the TPACK development across profiles.

#### 4.3.1. Results of the latent profile analysis (RQ1)

For RQ1, we identified a two-profile solution as most appropriate, following the evaluation steps as described in the previous LPA (chapter 4.2.1). Although five different VCM specifications (i.e., A, B, C, D, F) were theoretically possible (Table 3), we chose the two-profile solution with the *VCM specification F* due to statistical (lower BIC value and the highest entropy value) and practical factors. In detail, the *VCM specification F* offers the flexibility of profile-varying variances and covariances, i.e., given that pre-service teachers encounter learning experiences in seminars, it is the VCM specifications which account for the variability of responses and different interrelationships between different INQ dimensions across groups. Profile S1 (n = 135) is characterized by a high satisfaction with generic and rather moderate with content-specific INQ, whereas profile S2 (n = 75) reports highly satisfaction with all INQ dimensions (Fig. 2). Thus, S1 is named *Moderate Satisfaction* and S2 *High Satisfaction.*

#### 4.3.2. Results of the TPACK development across identified profiles (RQ2)

Results for the multi-group latent change model ($\chi^2$ (40) = 67.78, $p \le .05$; CFI = .98; TLI = .97; RMSEA = .06; SRMR = .06) for the satisfaction profiles revealed a significant difference of TPACK development between the two profiles (Wald-test: $\chi^2(1) = 7.07$, $p \le .05$). There is found a significant increase (S2; $ß_{\Delta TPACK} = .39$, $p \le .01$; 95% CI [.102; .674]; d = .31, $p \le .01$) in TPACK development among pre-service teachers in the *High Satisfaction* profile (S2, Fig. 2, Table 5), which is significant different to the stability of TPACK from the beginning to the end of the semester for pre-service teachers in the *Moderate Satisfaction* profile (S1; $ß_{\Delta TPACK} = -.10$, $p \ge .05$; 95% CI [-.312; .120]; d = −.08, *p* = n. s.). Controlling for covariates (i.e.,

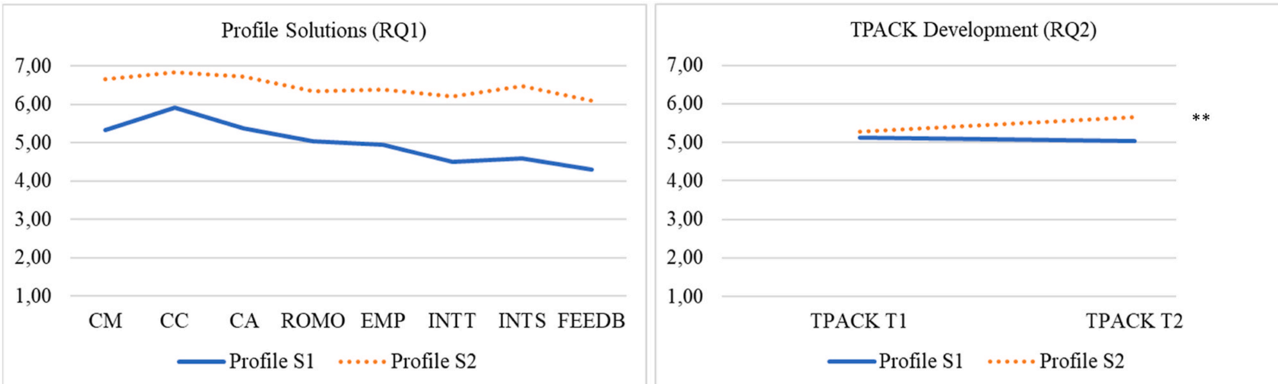


**Fig. 2.** *Two-Profile Solution for Satisfaction with Instructional Quality Dimensions* (RQ1) and Profile-Based TPACK Development (RQ2)
Note. $p \leq .05$ (*), $p \leq .01$ (**). Profile S1 = moderate satisfaction [n = 135] and Profile S2 = high satisfaction [n = 75].

**Table 5**
Step 2 (satisfaction): Estimated means and longitudinal change in TPACK across profiles.

| Factors | Approach F: 2-Profile Solution | | | | |
|---|---|---|---|---|---|
| | Profile S1 | Profile S2 | F (df) | *p* | Interpretation |
| | *M (SE)* | *M (SE)* | | | |
| CM | 5.34 (.10) | 6.65 (.05) | 84.43 (1, 207) | <.001 | S1 < S2 |
| CC | 5.92 (.09) | 6.85 (.04) | 57.23 (1, 207) | <.001 | S1 < S2 |
| CA | 5.38 (.10) | 6.73 (.06) | 92.62 (1, 207) | <.001 | S1 < S2 |
| RoMo | 5.05 (.12) | 6.34 (.08) | 54.74 (1, 204) | <.001 | S1 < S2 |
| Emp | 4.96 (.10) | 6.39 (.08) | 98.06 (1, 208) | <.001 | S1 < S2 |
| IntT | 4.51 (.14) | 6.21 (.11) | 64.12 (1, 166) | <.001 | S1 < S2 |
| IntS | 4.60 (.20) | 6.47 (.09) | 34.62 (1, 126) | <.001 | S1 < S2 |
| Feedb | 4.29 (.14) | 6.11 (.08) | 79.01 (1, 169) | <.001 | S1 < S2 |
| $TPACK_{t1}$ | 5.13 (.11) | 5.19 (.17) | | | |
| $TPACK_{t2}$ | 5.04 (.10) | 5.60 (.16) | | | |
| $ßΔ_{TPACK}$ | −.09 | **.41** | | | |

*Note.* N = 210. Profile S1 = moderate satisfaction [n = 135]; Profile S2 = high satisfaction [n = 75]. Estimated means from a scale from 1 to 7 for instructional quality dimensions and TPACK. Bold highlighted values are significant ($p \leq .05$). CM = Classroom Management, CC = Student Support, CA = Cognitive Activation, RoMo = Role Model, Emp = Empowerment, IntT = Interaction with Teachers, IntS = Interaction with Students, Feedb = Feedback, $TPACK_{t1}$ = TPACK first measurement point, $TPACK_{t2}$ = TPACK second measurement point, $ßΔ_{TPACK}$= Change of TPACK over time; F = test statistic for ANOVA; df = degrees of freedom; Interpretation = Profile comparisons indicate the relative order of mean values across profiles.

gender and semester of study) there was no change in results, i.e., indicating no impact of these covariates on TPACK development across profiles.

## 5. Discussion

The present study aimed to contribute to the understanding of the development of pre-service teachers' TPACK from a learning science perspective by considering experienced learning opportunities (i.e., INQ). As a first step, we examined profiles of pre-service teachers' experience of occurrence and satisfaction with both INQ perspectives (RQ1) and connecting it to pre-service teachers' TPACK development (RQ2).

In the following, we discuss our four main findings and its implications, i.e., (1) pre-service teachers differed in their learning experience, such that all experienced classroom management, student support and cognitive activation in seminars, but the SQD dimensions were heterogeneous in their occurrence, (2) when INQ was experienced, satisfaction was moderate to high level, never low, (3) when pre-service teachers report of the occurrence of all INQ dimension, they also show positive TPACK development trends, and (4) satisfaction of all INQ dimensions as the key component for TPACK development. The results will be discussed according to the research questions.

### 5.1. *The heterogeneity of instructional quality in teacher education (RQ1)*

Our study revealed heterogeneity of INQ across seminars emerging from distinct INQ dimensions. Previous research on K-12 mathematics teachers identified three profiles (low, medium, high) based on students' ratings of generic INQ of (Holzberger et al., 2019). Extending this work to higher education, we also included content-specific INQ. Contrary to findings from Holzberger and colleagues (2019), our results indicated homogeneous occurrence of generic INQ and high ratings in satisfaction of all three generic INQ dimensions. This means that pre-service teachers perceived classroom management, student support and cognitive activation as being present and of high quality across all seminars (Rubach et al., 2022). The lack of heterogeneity may be explained by the implementation of those practical guidelines, such as classroom management, which appear to be standard components in teacher education seminars in higher education. In our case, pre-service teachers were predominantly enrolled in educational sciences and in subject-specific pedagogy seminars, which might explain the application of generic, high quality teaching guidelines. Furthermore, our measurement represents the perspective of pre-service teachers who evaluated courses across the whole semester, around 14 weeks, whereas Holzberger and colleagues (2019) used data from teachers. Thus, we know that generic INQ is given, the intensity within each class from week to week stays unanswered.

In contrast to generic INQ, the five content-specific INQ dimensions based on the SQD-model showed high heterogeneity in the perception of occurrence across seminars, highlighting differences in seminar focus, variation in ICT integration and how these factors influenced pre-service teachers' perception of occurrence of content-specific INQ dimensions[6]. This may reflect Klieme and colleagues' notion (2001), that instructors tend to prioritize certain INQ dimensions. Such variation in priorities may arise for many reasons, for example their learning goals of individual seminars, which influence how instructors emphasize particular aspects of their instruction. This assumption is supported by the findings, that the *Low Occurrence* profile (O1) with low occurrence of content-specific INQ consists mainly of pre-service teachers in the

[6] ICC (1) indicated substantial between-seminar variability in content-specific INQ dimensions, consistent with the heterogeneity observed in the LPA. Guided by Morin & Wang (2016) we did not account for clustering in LPA class enumeration, but as suggested considered it in subsequent latent change models using the COMPLEX option (TYPE = COMPLEX). As results were identical, we report the models without accounting for clustering

control group (i.e., seminars) with no digital teaching focus in their courses. This aligns with findings from Tondeur and colleagues (2017b), who examined pre-service teachers' self-perceived TPACK in context of the teacher training program focusing on the SQD-model. Therefore, when analyzing and interpretating profiles in context of INQ, the used INQ dimensions and the intended learning outcomes may be worth to consider. Overall, this may support the theoretical suggestion that generic INQ is the basis for content-specific INQ dimensions as all identified profiles displayed variation in content-specific aspects, with at least one dimension occurring.

As a second result of RQ1, our study found two profiles (S1-S2) for satisfaction with generic and content-specific dimensions. These profiles highlight that whenever INQ dimensions occurred, pre-service teachers report medium to high levels of satisfaction. Interestingly, nearly two-thirds of pre-service teachers belong to the *Moderate Satisfaction* profile (S1), characterized by medium satisfaction of all INQ scales. Our findings suggest room for improvements in quality, particularly their perception of the five content-specific INQ dimensions. The distinction between occurrence and satisfaction of INQ dimensions in the analysis has key methodological, theoretical and practical implications. Because occurrence alone does not necessarily indicate satisfaction or well-received by learners, incorporating measures of both is needed allowing for more targeted evaluations of INQ.

In sum, the heterogeneity in perceived quality across all INQ dimensions indicates INQ is experienced subjectively in quantity and quality. Therefore, as a practical implication, we suggest that seminars may benefit from the regular assessment of pre-service teachers' perception of INQ during the semester, enabling the instructor to react and adapt their INQ dimensions accordingly. This is in line with Liu (2015) and Tondeur and colleagues (2021), who supported the need for evaluation of learning experiences in real-life settings. This need for individualized learning experiences, or in other words adaptive teaching, resonates with the instructor perspective on learning experiences, where Hill and colleagues (2012) argued that instructional proficiency is multidimensional. It further emphasizes the importance of understanding pre-service teachers' perceptions and aligning instructions with pre-service teachers' individual needs in context of INQ. This adaptivity and consequently the heterogeneity was also mentioned in the newly designed hybrid MAIN-TEACH model.

### 5.2. The relevance of generic and content-specific instructional quality for TPACK development (RQ2)

We identified differences in TPACK development between the four profiles for occurrence of content-specific INQ (O1-O4). Our hypothesis that both generic and content-specific INQ are crucial for TPACK development is not supported, as the *Low Occurrence* profile, i.e., O1, characterized by the occurrence of generic INQ but no occurrence of content-specific INQ (only limited *role models*), showed a negative (non-significant) trend of TPACK development. This result may confirm previous assumptions that generic INQ dimensions alone provide a necessary foundation but need to appear with content-specific INQ to foster TPACK development (Kyriakides et al., 2024).

Notably, also the *Low Interaction* profile (O2) showed a significant TPACK decrease with moderate change according to the Cohen's d value. This profile was characterized by medium occurrence of *role model* and *empowerment*, but low occurrence of *interaction with in-service teachers* and *students* at school as well as low *feedback* during the semester. These findings are in line with Agyei and Voogt (2012), who highlighted the importance of field experiences and interactions with in-service teachers for pre-service teachers' competence development. In general, there is a consensus that teachers (i.e., instructors) and their practiced INQ dimensions have a direct impact on students' (i.e., pre-service teachers) learning (Finkelstein et al., 2019). Moreover, pre-service teachers should get feedback about their TPACK, which helps them to evaluate and improve their competence (Kelleci Alkan et al., 2024; Tondeur et al., 2021). The present findings support this statement and extend it to higher education in university settings.

In contrast, the *Role Model and Empowerment Focused* profile (O3), with no occurrence of *interaction with students* but medium to high occurrence of the other subscales, showed a slightly positive trend of TPACK development. This somewhat unexpected result was non-significant, however, may indirectly support the previous assumption that interaction with teachers and role models are pivotal (Wang et al., 2018) and may have compensated for the missing interaction with students. Nevertheless, this interpretation should be treated with caution and requires further investigation.

The *High Occurrence* profile (O4), where all generic and content-specific INQ dimensions occurred, also showed a positive but non-significant trend in TPACK development. This finding suggests that single dimensions, as *role model*, alone nor the occurrence of them are not enough to foster pre-service teachers' TPACK. Instead, it supports previous findings (Hirsch & Rubach, 2024), indicating that it is not single dimensions but the orchestration of all five dimensions of content-specific INQ which contributes to the development of TPACK. This is in line with previous research (Buchner & Hofmann, 2022; Lachner et al., 2021; Tondeur et al., 2020), which highlighted the effectiveness of the SQD dimensions to foster pre-service teachers' TPACK. Additionally, by adding the generic perspective of INQ, our study demonstrates that TPACK development appears to benefit from the interplay of both INQ perspectives. However, given the non-significant results for profile O1, O3 and O4 these interpretations should be treated with caution.

As another key finding (RQ2), we suggest that occurrence of all INQ dimensions is not enough, but satisfaction is the key component for TPACK development. This is in line with the idea of person-environment fit (Rubach et al., 2022), who found that individualized feedback from instructors that fit pre-service teachers' needs results in positive learning outcomes. Results regarding satisfaction with INQ dimensions showed two different profiles: one with moderate satisfaction (*Moderate Satisfaction* profile; S1) and one with high satisfaction across all scales (*High Satisfaction* profile; S2). Only pre-service teachers belonging to the *High Satisfaction* profile (S2) indicated a significant positive TPACK development with moderate change according to the Cohen's d value. This aligns with previous research by Hirsch and Rubach (2024) who described that the orchestration of all INQ dimensions provide effective learning environments to foster TPACK development of pre-service teachers. Notably, pre-service teachers started with similar TPACK levels but differed in development depending on INQ experiences, indicating that trajectories depend on the quality and coherence of instruction (Sun et al., 2017). This finding aligns with assumptions from the person-environment fit theory, suggesting that misalignment between INQ dimensions and learners' needs can hinder professional growth (i.e., TPACK). Furthermore, the expressed need for high-quality instruction by well-trained instructors, role modeling, and authentic field experiences (e.g., interaction with in-service teachers) for TPACK development is supported by our findings (Agyei & Voogt, 2012; Tondeur et al., 2020). Taken together, TPACK development may be viewed as a reinforcing and ongoing cycle where instructors have to be well trained and perceive themselves with higher levels of TPACK to display generic INQ (Sacré & Lallemand, 2023), which builds the foundation for content-specific INQ. The instruction of both INQ dimensions in orchestration promotes pre-service teachers' TPACK, who in turn, as future instructors (i.e., teachers) continue the cycle by applying these dimensions in their classrooms fostering their students' TPACK development.

### 5.3. Limitations and future steps in teacher education research

Despite these findings, limitations must be acknowledged. First, the study used data from one university in Germany, i.e., one curriculum and contextual factors at the institutional level, which may limit the generalizability of the findings to other institutions or countries. But notably, as stated before, previous research has highlighted that learning experiences, or in other words experienced INQ dimensions, are important for TPACK development (Rubach et al., 2022; Sun et al., 2017), suggesting comparable trends across contexts. Furthermore, the study did not capture the full range of seminars offered at the University of Rostock. We focused solely on seminars addressing ICT in the chosen two semesters, including a control group for each investigated group without ICT focus. A comprehensive coverage of all seminars offered at the University of Rostock was not the aim of the study and not feasible of the many elective options of seminars offered across the teacher education programs. This aligns with Drahmann (2020), who notes the structural heterogeneity of German teacher education programs, characterized by optional modules and low coherence across universities. Therefore, it would be interesting to explore which learning experiences are provided in different universities and countries and how these shape pre-service teachers' TPACK development.

In line with previously mentioned limitations, we also acknowledge that our analysis focused only on selected aspects of the university's instructional practices. Specifically, we considered seminars but did not include lectures, considering an equal instructional environment as they may have different didactical design possibilities. Additionally, we examined whether a seminar included a digital focus, but we did not take into account the specific content or methods as surface structures (Klafki, 1964, 1986). As Praetorius and colleagues (2018) argue, INQ is not fully captured by INQ dimensions alone; the content of instruction and its correctness represent additional essential aspects that need to be taken into account. Consequently, our study does not capture the full range of potentially relevant indicators to understand pre-service teachers' TPACK development. Future research should explore the specific content and methods of seminars and lectures presenting these INQ dimensions and its relation to pre-service teachers' TPACK development. Furthermore, it would be interesting to verify how stable the identified profiles are and how possible changes impact self-perceived TPACK of pre-service teachers. For example, future research could explore whether the satisfaction of INQ dimensions changes from middle to end of the semester and how such changes affect self-perceived TPACK.

Another limitation concerns the assessment of TPACK, which was measured solely through self-reported measures. Thus, our instruments capture motivational beliefs as one aspect of competence, rather than the full construct of competence, which also includes knowledge and situation-specific skills. Therefore, developmental differences identified in this study should be interpreted with a focus on changes in self-perceptions rather than changes in knowledge or situation-specific skills. Consequently, self-perceived TPACK may not fully reflect enacted TPACK, that is, how (pre-service) teachers actually apply TPACK in authentic classroom interactions. Future research should therefore complement self-perceived measures of TPACK with both knowledge-based and practice-oriented assessments of enacted TPACK. This includes knowledge tests (e.g., Fütterer et al., 2023; Lachner et al., 2021) as well as practice-oriented approaches such as planning-, implementation-, or observation-based measures (e.g., the EnTPACK rubric; Aumann et al., 2023). Assessing competence across its different components would allow for a more comprehensive understanding of (pre-service) teachers' TPACK. In the future, combining these approaches may be particularly valuable for investigating the effectiveness of seminar designs in teacher education.

Another limitation lays in the used items for generic and content-specific INQ: For generic INQ we asked pre-service teachers how the instructor performed directly, i.e., the offering of learning experiences, whereas for content-specific INQ we asked for pre-service teachers' actual use of the offered learning opportunities. For future research, it may be interesting to compare pre-service teachers' feedback of instructors INQ and instructors' self-perception of their performance as it could help identify potential discrepancies between perception and evaluation, helping to improve INQ of higher education. Furthermore, future research could extend this approach by applying multilevel mixture models to more directly capture group-level influences. In particular, instructor characteristics may represent an important contextual factor as differences in instructional style and pedagogical experience may systematically influence how pre-service teachers perceive INQ. In addition, it may be worth considering the potential influence of the so-called halo-effect (Nisbett & Wilson, 1977) in pre-service teachers' evaluation of INQ dimensions. Previous research found that students, in this study pre-service teachers, base their evaluations on a single prominent dimension or characteristic and overall impression (Keeley et al., 2013). Another study highlighted that INQ ratings are context-dependent and influenced by characteristics of both the course and the rater itself (Rubach et al., 2025). Furthermore, the items for satisfaction of INQ measured pre-service teachers' satisfaction but not the frequency of which INQ dimensions are offered. Future research should therefore investigate to what extent and how often INQ dimensions need to be addressed in seminars to foster high levels of satisfaction with INQ dimensions and TPACK development. Although occurrence is considered a low-inference measure, it depends on pre-service teachers' perception, meaning we cannot be certain that reported INQ were objectively observed, only it reflects participants' recognition and interpretation of instructional practices. Moreover, the interpretation of satisfaction is subjective. As a limitation, we cannot conclusively determine how instructors should integrate both INQ perspectives across seminars. Further research is needed to explore how different course designs, context and INQ dimensions influence the effective incorporation of both INQ dimensions. In addition, the low variance of generic INQ dimensions raised the question of how such limited variability should be handled in future analysis. From a research perspective, these findings call for a closer examination of how generic and content-specific INQ dimensions develop and interact within university-based settings. Furthermore, rather than creating additional models which display our results, efforts should focus on refining and extending existing comprehensive frameworks, such as the SQD-model and TBD framework, and updating them with current and future empirical findings. Consequently, teacher education programs may benefit from placing stronger emphasis on content-specific dimensions, where variation is more likely to occur.

## 6. Conclusion

The value of this study lies in the analysis of generic and content-specific INQ perspectives together, showing that generic INQ occurs more frequently and receives consistently high satisfaction, while content-specific INQ varies across profiles in both occurrence and satisfaction. Furthermore, pre-service teachers' TPACK development depends on both INQ perspectives, in particular on pre-service teachers' satisfaction with INQ. These insights could help teacher education to develop targeted support for pre-service teachers' TPACK development and may serve as an approach for evidence-based development and monitoring. In conclusion, this study provides evidence that INQ is meaningfully related to the development of pre-service teachers' TPACK in teacher education.

## CRediT authorship contribution statement

**Anne-Kathrin Hirsch:** Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Jo Tondeur:** Writing – review & editing, Conceptualization. **Charlott Rubach:** Writing – review & editing, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization.

## Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work the authors used *Research Rabbit* and *ChatGPT 4.0* in order to find related research and to improve grammar and spelling to provide a fluent readable manuscript.

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## Declaration of competing interest

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

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tate.2026.105620.

## Data availability

Data of the associated project can be seen in the pre-registration at OSF under following link: https://osf.io/z78ne

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