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What Do the Relationships between Pre-Service Biology Teachers' Personality and Professional Knowledge Reveal about Their Innovativeness?—An Exploratory Study Using Canonical Correlation Analysis

Virginia Deborah Elaine Welter [1,*,†], Lars Emmerichs [2,†] and Kirsten Schlüter [2]

[1] Department of Biology Education, IPN—Leibniz Institute for Science and Mathematics Education, 24118 Kiel, Germany
[2] Institute of Biology Education, University of Cologne, 50931 Cologne, Germany; lars.emmerichs@uni-koeln.de (L.E.); kirsten.schlueter@uni-koeln.de (K.S.)
* Correspondence: welter@leibniz-ipn.de
† These authors contributed equally to this work.

Abstract: Already in 2016, the German educational policy adopted the Education in the Digital World strategy, recommending that all teachers should become experts in using media. However, despite this initiative regarding the promotion of innovative forms of teaching using digital media, most teachers did not feel optimally prepared to successfully cope with the demands of implementing e-learning during the COVID-19 pandemic. Most empirical studies on potential barriers to innovation pertain to comparatively easy, changeable environmental factors, whereas only a few studies have focused on teachers as an individual factor so far. Since several organizational psychological studies on the relationships between innovativeness and personality traits in professional contexts identified the personality trait of openness to experience to be particularly influential on the innovative behaviors of employees', our study aimed to explore whether comparable results can also be found in the educational context. Therefore, we conducted a cross-sectional survey (n = 201) to analyze to what extent the Big Five personality traits are related to pre-service teachers' self-concept of professional knowledge and, in particular, its digitalization-related domains. The results of our canonical correlation analysis show that the two personality traits of openness to experience and conscientiousness appear to be significantly related to the overall professional knowledge of our sample. Furthermore, a dominant affinity for technology seems to be associable with the risk of lower values on personality traits that are regarded to be pedagogically relevant. However, we found that our canonical model could also get along with fewer variables since the actual digitalization-related teaching skills were not sufficiently reflected by the canonical solution but were rather caught up in the domain of pedagogical content knowledge. Interpretations of these findings as well as practical implications are discussed.

Keywords: pre-service teachers; innovativeness; Big Five personality traits; self-concept of professional knowledge; digitalization-related skills; canonical correlation analysis

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1. Introduction

Digitalization is considered a paradigmatic field of innovation [1–4]. The extent to which digital technologies are assimilated or accepted as innovations and finally can be used profitably, depends on both material conditions (e.g., sufficient infrastructure) and personal factors on the part of the users. Besides, for example, basic IT operation skills, a reflected use also requires an awareness of the mechanisms and potentials of digital technologies as well as the willingness to deal with ongoing technological progress [2]. Thus, it becomes understandable that a profitable use of digital technologies often requires extensive learning and competence development [5–7].

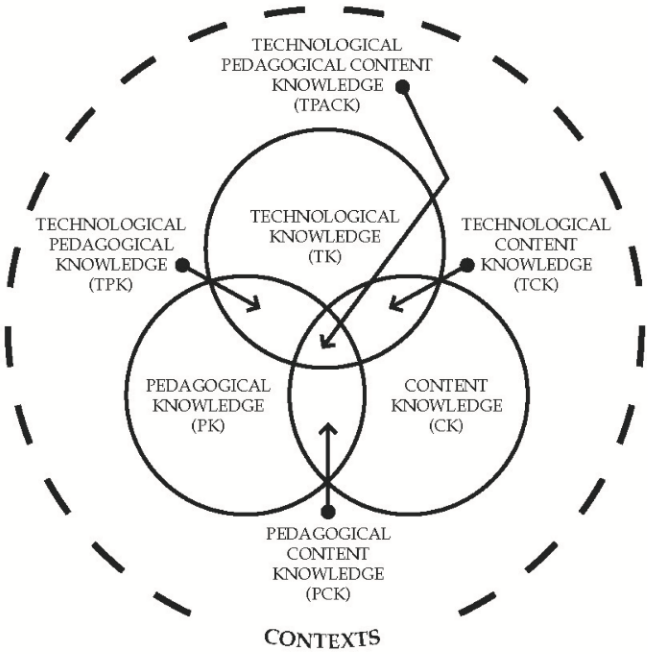
The whole extent to which private and professional life is shaped and claimed or could be facilitated by digital technologies was impressively revealed during the COVID-19 pandemic: many employees worked from home; e-commerce became a common standard; and meetings, conferences, trade fairs, concerts, church services, and much more temporarily took place online in many countries [8]. Especially the education system was challenged by the public expectation to maintain school and university education by quickly shifting regular on-site teaching to e-learning offers [9]. Already in 2016, German educational policy adopted the Education in the Digital World strategy, recommending that all teachers should become "media experts" (p. 24) regarding teaching and learning in their respective teaching subjects [10]. However, despite this initiative regarding the promotion of innovative forms of teaching using digital media, three years later most teachers did not feel optimally prepared to successfully cope with the abrupt demands of implementing COVID-19-related e-learning [11,12]. What has been carried out (comparatively spontaneously and unprepared) in this regard, including its functionality for teachers, students, and their teaching and learning success, is a matter of current deficit analyses at various levels [9,13–16].

On the one hand, potential barriers to innovation can certainly be attributed to structural conditions, i.e., environmental factors such as social and political structures, technical infrastructure, or the school itself and its organizational specifics [17]. On the other hand, these barriers also seem to be related to personal conditions, i.e., individual factors on the part of the (aspiring) teachers, including aspects of their professional competence as well as personality traits [17–19]. Most empirical studies on this issue pertain to the first-mentioned (comparatively easy changeable) environmental factors in order to efficiently derive measures for school development [20]. In contrast, only a few studies have systematically focused on teachers as an individual factor so far, although the identification of relevant personal characteristics influencing innovative behavior seems crucial as well [21–23]. For example, the challenge of digital change requires a specific individual willingness and ability to both adapt to changed options for action and to actively support as well as help to shape innovations, if necessary [6,7].

1.1. Teachers' Professional Knowledge and Digitalization-Related Skills

In order to shift the increasingly important field of digital teaching and learning away from a kind of implicitness toward an appropriate integration into the skills profile of teachers, Mishra and Koehler [24] proposed their Technological Pedagogical Content Knowledge (TPACK) model. Basically, TPACK is an extension of Shulman's [25,26] well-known classification of teachers' professional knowledge, stating pedagogical content knowledge (PCK) to be the teacher's ability to make subject matter knowledge understandable for learners by considering their individual characteristics, such as interests or prior knowledge. Thus, PCK includes, for example, knowledge about difficulties of learners, about common misconceptions, or about the appropriateness of using certain concepts, pictorial representations, examples, analogies, and metaphors when teaching a specific topic. This combination of teachers' subject-related content knowledge (CK) and elements of cross-disciplinary pedagogical knowledge (PK) constitutes PCK as an independent domain of professional knowledge [27,28] that relates to a teacher's ability to facilitate the learners' meaningful learning of a respective subject [25,26]. According to this PCK construct in terms of Shulman [25,26], TPACK is also regarded as an independent domain of teacher knowledge but relates to the successful integration of subject–specific content, pedagogical aspects, and technological expertise [29–31] (see Figure 1).

Most of the recent conceptualizations and initiatives of educational policy cover the TPACK model's domains, but some of them even go beyond Mishra and Koehler's [24] framework. For example, the European Framework for the Digital Competence of Educators (DigCompEdu) [32] additionally specifies aspects such as organizational communication, formative evaluation of digital teaching and learning, or promotion of learners' digital competence, as these are regarded to significantly complement successful teaching and learning using digital technology [32,33].



TK	Knowledge of the functionality, application, and possibilities of hardware, software, and associated technology
CK	In-depth knowledge and understanding of the discipline to be taught
PK	Knowledge about learning and learners, classroom management, educational psychology, and development processes
PCK	Knowledge of how to deal with subject-specific knowledge in the classroom; knowledge of the conceptual ideas of learners and specific instruction strategies
TCK	Knowledge of how specific technologies can be used to design and to present subject-specific content effectively
TPK	Knowledge of different technologies and their potential for the design of learning environments; knowledge of problems and constraints related to technology when used for learning
TPACK	Knowledge of how to use certain technologies to support learners' knowledge acquisition and overall learning success

Figure 1. Domains of knowledge considered in the TPACK model [24].

1.2. Personality in Research on Teachers' Professional Competence

In accordance with current models of teachers' professional competence [19], the cognition-related knowledge base (CK, PK, PCK, etc.) is regarded to be supplemented by further motivational and attitude-related aspects of competence, such as self-efficacy, enthusiasm for teaching, or epistemological beliefs. Besides, variables that can be attributed to a narrower dimension of personality are also gaining in importance in research on teachers' professional competence [21,34–37]. However, such a consideration of personality traits in teachers' skills profiles no longer relates to the idea of charisma, which many adhered to well into the 20th century [38,39], but, for example, addresses the empirical finding that good self-regulation skills are decisive resources for coping with professional demands and achieving high quality teaching [40].

Research on personality traits belongs to the field of differential and personality psychology, which investigates intraindividual characteristics in peoples' experience and behavior as well as related interindividual differences. Corresponding descriptions, explanations, and predictions of personality-related phenomena are predominantly based on the trait theory since the trait concept allows for more general statements than those that only refer to idiosyncratic behavior in specific situations. Accordingly, the trait theory regards a personality trait as a person's disposition or willingness to behave in a characteristic way when being confronted with comparable classes of situations. Thus, personality traits include comparably stable interindividual differences in temperament, motives, interests, beliefs, attitudes, values, and general mental state [41–43].

Following the well-established Big Five model of personality, everyone can be characterized on a total of five cross-culturally replicable dimensions [44,45]:

1. Neuroticism (anxiety, irritability, depression, social bias, impulsiveness, vulnerability);
2. Extraversion (cordiality, sociability, assertiveness, activity, love of adventure, cheerfulness);
3. Openness to experience (imagination, curiosity, interest in aesthetics such as art, music, and poetry, preference for variety instead of routine);
4. Agreeableness (faithfulness, cooperativity, altruism, modesty, kindness);
5. Conscientiousness (tidiness, sense of duty, need for achievement, self-discipline, considerateness).

Despite their replicability and cross-cultural stability, the Big Five (in contrast to constructs such as self-regulation or enthusiasm for teaching) have so far only been rarely considered in research on teachers' professional competence [46]. For example, Kim et al. [47] conducted a comprehensive meta-analysis of 25 studies on the relationships between teachers' Big Five personality traits and the two job-related outcomes of teacher effectiveness and teacher burnout. Whereas the authors found the Big Five domains of emotional stability (i.e., low neuroticism), extraversion, openness to experience, and conscientiousness to be positively related to teacher effectiveness, the outcome of teacher burnout appeared to be negatively associated with emotional stability, extraversion, and conscientiousness. Furthermore, in their longitudinal study over 10 years, Roloff et al. [48] investigated the predictive validity of more than 3000 students' personality, cognitive skills, and academic abilities at the end of high school on their later instructional quality after finishing teacher training. Complementing Kim et al.'s [47] results, Roloff et al. [48] found especially agreeableness to be predictive for teachers' abilities in creating a supportive social environment for their students. Moreover, in a study focusing on mathematics teachers, Baier et al. [49] investigated the predictive validity of teacher characteristics (cognitive ability, personality, professional knowledge, beliefs about teaching, and enthusiasm for teaching) on their instructional quality (learning support, classroom disruptions, and cognitive activation) rated by their students. Regardless of other significant predictor variables, they found extraversion to be positively associated to learning support whereas conscientiousness turned out to be significant regarding classroom discipline. In addition, in their study on associations between personality traits and beginning teacher performance as well as career continuance, Bastian et al. [50] found conscientiousness to be significantly related to higher teacher value-added estimates, higher evaluation ratings, and higher retention rates of first-year public school teachers.

Regardless of these interesting findings, however, most studies on teachers' professional competence do not take the Big Five into account. One reason for this may be the widely held belief that personality traits are rather stable over time, thus difficult to change and therefore of little practical relevance [38]. However, regarding the question of alterability, *relative* stability is indeed a theoretically and pragmatically decisive parameter of personality, but, at the same time, this relativity offers possibilities for further even intentional change [51–54]. Since coaching and/or personality development offers have been successfully taken up in several professional fields for many years [55–57], it seems reasonable to explore whether and to what extent there are corresponding action-oriented starting points within the framework of teacher education.

1.3. Relationships between Personality Traits and Innovativeness

The relationships between personality traits and innovativeness have so far mainly been addressed by organizational psychological research within the economic context, so study participants have typically been considered in sectors other than education. Some of these studies could, for example, show that high levels of personal competence such as communication skills, personal responsibility, perseverance, creativity, flexibility, and curiosity are positively associated with the willingness of employees to use new products, procedures, or services and deal successfully with them [58–64].

Regarding the specific relationships between innovativeness and Big Five personality traits, there is a heterogeneous picture of findings, which is most likely caused by both differences in research methods and a dependence of the relationships on the respective job sector [62]. For example, Hsieh et al. [65] found openness to experience, extraversion, and conscientiousness to particularly influence innovative behavior among Taiwanese biotech employees, whereas Chen et al. [66] found significant effects of openness to experience, extraversion, and agreeableness (instead of conscientiousness) on innovative behavior of employees in Taiwan's maritime tourism sector when developing and selling ideas. In contrast, based on her analysis of data from hotel employees in Amsterdam, Baks [67] summarizes that both high levels of openness to experience and low levels of neuroticism are

the most decisive predictors of innovative behavior, whereas Munir and Beh [68] found only openness to experience significantly associated with innovative behavior of employees of a Malaysian automotive supplier. Furthermore, Woods et al. [69] found that the duration of employment of employees of a British finance company positively moderated the influence of openness to experience on the development of ideas, i.e., the more pronounced openness to experience and the longer the duration of employment, the more innovative ideas were developed. In addition, they found that the duration of employment negatively moderated the influence of conscientiousness on the development of ideas, i.e., the more pronounced conscientiousness and the longer the duration of employment, the fewer innovative ideas were developed. These results demonstrate that, besides the differential effects of research methodologies and the respective job sector, other moderating factors must also be taken into account when looking at the relationships between the Big Five and innovativeness. In this respect, Waßmann [64] presented very differentiated effects regarding his 4-cluster solution for describing the innovation type of employees considering seven innovativeness-related aspects: (1) creativity, (2) absence of mental blocks, (3) social competence, (4) need for achievement, (5) methodical competence, (6) ability to cooperate, and (7) communication skills. For example, one cluster (low innovativeness) is characterized by above-average neuroticism scores along with below-average extraversion scores, and average scores on the remaining three Big Five dimensions. Another cluster (high innovativeness) is composed of below-average values for neuroticism but above-average values for all other Big Five dimensions. In particular, openness to experience is above average in the two clusters that are most closely associated with innovativeness.

In summary, research to date presents a large number of fragmentary results, some of which are complex to interpret. Nevertheless, this heterogeneous picture offers a repetitive quintessence: especially the Big Five factor of openness to experience consistently turned out to be particularly influential on employees' innovative behavior [62].

1.4. Research Question

In our study, we take up these empirical findings on the relationships between innovativeness and personality traits in professional contexts. Since authors of several studies [47–50] have already pointed out that neither the experiential framework nor the professional demands in organizations other than schools can per se be considered equivalent or comparable to those of the teaching profession, we want to investigate whether comparable results can also be found in the educational context of university teacher training. Since the field of digital teaching and learning is regarded paradigmatic for the construct of innovation in education [70–73], we chose pre-service teachers' digitalization-related skills as appropriate operationalization of innovativeness (see Section 2.1). Specifically, we ask the following research question: To what extent are the Big Five, perhaps also beyond openness to experience, related to pre-service teachers' self-concept of professional knowledge and, in particular, its digitalization-related domains? Answering this question may allow deriving recommendations regarding didactical approaches or training elements focusing on personality development to qualify aspiring teachers, as it were, for acting as 'agents of change' during their professional careers.

2. Materials and Methods

In the period from 2018 to 2021, we repeatedly conducted cross-sectional surveys of several (basically comparable) cohorts of pre-service teachers. These surveys always took place as part of the same courses of the Institute of Biology Education at our university, which were offered one time per academic year and should be completed by each student at a defined point in his or her teacher education program (nonrecurring participation). With this study, we originally wanted to not only answer the question about existing relationships between personality traits and innovativeness but also to check whether both these connections and the scores achieved on the respective constructs vary between the different cohorts over time (e.g., systematically toward higher or lower values). However,

COVID-19's unpredictable outbreak frustrated our plans by dramatically altering both pre-service teachers' personal situation and university learning [8,74–80]. This made it impossible for us to validly compare data collected before March 2020 with data collected after. We, therefore, decided to use the collected data in two ways: On the one hand, we used the overall collected data (N = 395) in a previous study report that specifically focused on COVID-19-associated changes in pre-service teachers' self-concept of professional knowledge [15]. On the other hand, we would now like to refer only to that part of the total data (n = 201) that was collected prior to the COVID-19 pandemic (in the period from 2018 to 2019). These data, however, do not allow anymore for considering possible variations in the constructs or their relationships over time, but they do allow us to answer the general question about the relationships between pre-service teachers' personality traits and innovativeness.

Approximately 77% of the n = 201 pre-service biology teachers were female, 22% were male, and 1% was non-binary gender. On average, the participants were 22.38 (SD = 2.58) years old and had already completed slightly more than half of their undergraduate studies. All of them were asked to complete an online questionnaire covering both their self-concept of professional knowledge, including digitalization-related skills, and the Big Five personality traits. For this purpose, we used the Qualtrics Survey software (SAP America, Newtown Township, PA, USA) [81].

2.1. Questionnaires

The Big Five personality traits were assessed using the German version of the NEO Five-Factor Inventory (NEO-FFI) [82], comprising self-assessments on five 12-item scales. These 60 items should be rated each on a 5-point Likert scale (0 = *strongly disagree* to 4 = *strongly agree*). The NEO-FFI's objectivity, factorial structure, and validity are supported by previous findings [82,83]. The homogeneity of the five subscales ranged between α = 0.72 and 0.85 in our sample.

To assess the pre-service teachers' self-concept of professional knowledge, including digitalization-related skills, we used a questionnaire by Schmidt et al. [84], whose items relate to the seven dimensions of the TPACK model (see Figure 1). A previous validation study confirmed the instrument's objectivity, factorial structure, and validity [84]. In our study, we adopted the TK, PK, and TPK subscales without any changes, whereas items for the assessments of the remaining subject-specific dimensions (CK, PCK, TCK, and TPACK) were specifically adapted for the subject of biology (by replacing the original subjects of mathematics, social studies, science, and literacy by those areas with which our pre-service biology teachers were familiar: botany, zoology, and human biology). The final version of our questionnaire comprised overall 40 items, which should be rated each on a 7-point Likert scale (1 = *strongly disagree* to 7 = *strongly agree*). The homogeneity of the seven subscales ranged between α = 0.77 and 0.89 in our sample.

2.2. Statistical Methods

To answer the question of the relationships between the pre-service teachers' Big Five personality traits and their self-concept of professional knowledge, including digitalization-related skills, we conducted a canonical correlation analysis (CCA) using IBM SPSS Statistics 28 (IBM Corp., Armonk, NY, USA) [85]. In contrast to the standard Pearson correlation coefficient r, which measures the extent to which two single variables are related, a CCA is a multivariate procedure, determining the relationship between two sets of variables.

First of all, we checked our data for meeting the assumptions of CCA:

1. CCA requires a large sample size to avoid Type II errors when generating the model [86,87]. In cases of large effects (canonical correlations > 0.70), n = 50 is considered to be sufficient, whereas medium or small effects require at least 10 to 20 times as many cases as variables in the analysis [88,89]. Since we included 12 variables in our CCA, we regarded our sample size of n = 201 to be adequate;

2. CCA assumes linear relations among the variables [87,88], so we screened the scatter plots of each pair of variables for non-linear patterns. However, since we did not find any curvilinear patterns, we considered the linearity assumption to be sufficiently met;
3. CCA works best when the relationships between the variables considered are homoscedastic [87]. We controlled for heteroscedasticity by ascertaining that the residual plots of any pairs of variables within and between the two sets show random patterns;
4. Multicollinearity among a set's variables can compromise a CCA's ability to estimate reliable weights of any single variable within this set [86]. Therefore, we calculated the variance inflation factor (VIF) for each set of variables, separately. In general, a VIF of 1 indicates the absence of multicollinearity, whereas VIFs > 1 indicate existing correlations among variables of a set [90]. There are no clear criteria to certainly decide that a VIF is too large: Whereas most authors recommend eliminating variables whose VIF is >10, some others prefer a very conservative level of VIF > 2.5, especially for weak models [91,92]. In our study, the NEO-FFI set's variables' VIFs ranged from 1.00 to 1.36, and those of the TPACK set's variables ranged from 1.45 to 2.69 (with only one VIF > 2.5). Thus, prior to running CCA, we could rule out problems with multicollinearity on an almost certain level;
5. Although a CCA does not assume any special distribution for estimating the model, the associated significance tests require multivariate normal distribution of the variables. We checked this by running a Henze–Zirkler test, using the R package "mvn" [93]. Since this test rejected the multivariate normal distribution of our variables, we explored every single variable's distribution, considering skewness and kurtosis parameters. This exploration showed that 10 of the 12 variables related to skewness and kurtosis parameters that did not significantly exceed |1.0| (most of them ranged close to 0), which indicated at least rough fits of the bell curve [87]. For the remaining two variables (PK and TPK of the TPACK set), the skewness parameters were also within an acceptable range, but the kurtosis was around |2.0| in the case of PK, and around |1.6| in the case of TPK. These two deviations plausibly explain why the Henze–Zirkler test rejected the multivariate normal distribution. However, since CCA results are usually quite robust if a sufficient sample size has been reached [94,95], we decided to run the CCA despite these violations. Furthermore, in making this decision, it was also important to weigh up the alternative: Whereas CCA allows for both preventing alpha-error accumulation and considering interdependencies between variables that belong to one set, the calculation of all possible bivariate correlations between the variables does not, possibly leading to even more unreliable results of significance tests [87,96–98].

To prepare our CCA, we built two sets of variables (see Table 1): The first one included the five *z*-standardized subscale scores of the NEO-FFI questionnaire [82], the second one included the seven *z*-standardized subscale scores of the TPACK questionnaire [84].

Table 1. Overview of the variables' assignments to the two CCA sets.

Set *X* (NEO-FFI Subscales)	Set *Y* (TPACK Subscales)
Neuroticism (x_1)	TK (y_1)
Extraversion (x_2)	CK (y_2)
Openness (x_3)	PK (y_3)
Agreeableness (x_4)	PCK (y_4)
Conscientiousness (x_5)	TCK (y_5)
	TPK (y_6)
	TPACK (y_7)

Annotation. TK = technological knowledge; CK = content knowledge; PK = pedagogical knowledge; PCK = pedagogical content knowledge; TCK = technological content knowledge; TPK = technological pedagogical knowledge; TPACK = technological pedagogical content knowledge.

To clarify the relationships between sets of variables using CCA, each set's variables are assigned canonical weights β_{ij} to generate an optimal linear combination within every

set [97]. The criterion for optimality here is a maximization of the canonical correlation R_C between the resulting two canonical variates X^* and Y^*. Thus, the basic model in our study can be described as:

$$X^* = \beta_{x_1} \cdot x_1 + \beta_{x_2} \cdot x_2 + \beta_{x_3} \cdot x_3 + \beta_{x_4} \cdot x_4 + \beta_{x_5} \cdot x_5$$

$$Y^* = \beta_{y_1} \cdot y_1 + \beta_{y_2} \cdot y_2 + \beta_{y_3} \cdot y_3 + \beta_{y_4} \cdot y_4 + \beta_{y_5} \cdot y_5 + \beta_{y_6} \cdot y_6 + \beta_{y_7} \cdot y_7$$

The canonical correlation R_C between the two variates X^* and Y^* corresponds to the usual bivariate Pearson correlation coefficient ($0 \leq R_C \leq 1.0$). Accordingly, R_C^2 is a measure of the shared variance of X^* and Y^* [96,98–102].

The maximum number of predictable canonical correlations corresponds to the number of variables in the smaller set. These possible canonical correlations are obtained successively by the CCA algorithm: After the first maximum canonical correlation R_{C_1} of the first two canonical variates X_1^* and Y_1^* is calculated, $R_{C_1}^2$ reflects the shared variance in this first canonical correlation. However, after this procedure, there may be a significant amount of residual variance between the two sets of variables. In this case, a second pair of variates (X_2^* and Y_2^*) is constructed. As X_2^* and Y_2^* are built orthogonal to X_1^* and Y_1^*, the resulting $R_{C_2}^2$ explains maximum residual variance of the first-generation variates. If, after the second canonical correlation, there is still remaining residual variance to be explained, a third pair of variates (X_3^* and Y_3^*) is constructed and correlated with each other, and so on [96,98–102].

For the sake of simplicity, further explanations on specific CCA indices and the informative value of canonical solutions are taken up in the following results section.

3. Results

To get an initial overview of the data structure, we first determined relevant descriptive measures of the set variables considered as well as all pairwise bivariate correlations between them (see Section 3.1). Afterward, we conducted the CCA whose results are reported in Section 3.2.

3.1. Descriptive Statistics and Bivariate Pearson Correlations

Regarding the Big Five personality traits, descriptive statistics (see Table 2) show that the pre-service teachers on average achieved the highest scores on the dimensions of agreeableness (M = 34.04, SD = 5.65) and conscientiousness (M = 32.63, SD = 6.13). In contrast, neuroticism was by far the least expressed, but showed the largest variability (M = 20.42, SD = 7.62). With regard to the self-concept of professional knowledge, including digitalization-related skills, a very homogeneous response pattern of exclusively medium (=*neutral*) to slightly positive assessments resulted on all seven scales.

The bivariate correlation analysis (see Table 3) revealed only a few significant correlations among the Big Five variables, whereas those of the TPACK model showed many moderate and sometimes high correlations among each other. However, we still did not assume a significant multicollinearity problem (see Section 2.2), since such a problem only seems likely in case of correlations of $r \geq 0.80$ [103]. Regarding the correlations between the Big Five and the TPACK variables, we found positive relationships between conscientiousness and all TPACK scales except TK and TCK, as well as between openness for experience and TK, CK, and PCK. On the other hand, negative correlations resulted for neuroticism and TPK as well as for agreeableness and TK. Overall, however, the significant bivariate intercorrelations turned out to be predominantly small in reaching values between $r = |.16|$ and $|.31|$.

Table 2. Means and standard deviations of variables belonging to the Big Five personality and the TPACK model.

Construct(s)	Variable	*M*	*SD*
Big Five personality traits	Neuroticism	20.42	7.62
	Extraversion	29.79	5.80
	Openness	28.62	5.85
	Agreeableness	34.04	5.65
	Conscientiousness	32.63	6.13
Self-concept of professional knowledge, including digitalization-related skills	TK	4.27	1.21
	CK	4.63	0.82
	PK	5.19	0.85
	PCK	4.99	0.90
	TCK	4.56	1.16
	TPK	5.01	0.90
	TPACK	4.78	1.01

Annotation. TK = technological knowledge; CK = content knowledge; PK = pedagogical knowledge; PCK = pedagogical content knowledge; TCK = technological content knowledge; TPK = technological pedagogical knowledge; TPACK = technological pedagogical content knowledge.

Table 3. Bivariate Person correlations of variables belonging to the Big Five personality and the TPACK model.

	N	E	O	A	C	TK	CK	PK	PCK	TCK	TPK	TPACK
N	—											
E	−0.41 ***	—										
O	−0.03	0.04	—									
A	−0.09	0.32 ***	0.05	—								
C	−0.24 ***	0.23 **	−0.02	0.17 *	—							
TK	−0.12	−0.12	0.21 **	−0.20 **	−0.05	—						
CK	−0.10	0.06	0.29 ***	0.04	0.31 ***	0.30 ***	—					
PK	−0.05	0.07	0.08	0.07	0.21 **	0.11	0.39 ***	—				
PCK	−0.11	0.05	0.17 *	−0.07	0.23 **	0.10	0.51 ***	0.56 ***	—			
TCK	−0.01	−0.08	0.14	−0.03	0.10	0.38 ***	0.30 ***	0.40 ***	0.44 ***	—		
TPK	−0.16 *	0.00	0.12	0.04	0.19 **	0.43 ***	0.47 ***	0.64 ***	0.52 ***	0.58 ***	—	
TPACK	−0.05	−0.10	0.10	−0.05	0.21 **	0.31 ***	0.51 ***	0.49 ***	0.60 ***	0.56 ***	0.60 ***	—

Annotation. N = neuroticism; E = extraversion; O = openness to experience; A = agreeableness; C = conscientiousness; TK = technological knowledge; CK = content knowledge; PK = pedagogical knowledge; PCK = pedagogical content knowledge; TCK = technological content knowledge; TPK = technological pedagogical knowledge; TPACK = technological pedagogical content knowledge; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

3.2. Canonical Correlation Analysis

The starting point for the evaluation of a canonical solution is the rejection of the null hypothesis that there is no relationship between two sets of variables, i.e., the variates X^* and Y^* [97]. With $\lambda_{\text{Wilks}'} = 0.61$, our CCA showed a significant result for the overall model, which comprised a total of five canonical functions. This corresponds to an overall variance explanation of $R^2_C = 1 - \lambda_{\text{Wilks}'} = 0.39$ (= 39%) by the five successive pairs of canonical variates. Considering the set sizes in our study of five and seven variables, this R^2_C value relates to a medium effect size of $f^2 = 0.13$ [104] for the overall model.

The next step was to decide which of the five canonical functions explain a significant amount of variance. The results of the dimension reduction analysis (see Table 4) revealed that only the first two canonical functions reached this level of statistical significance, which is also reflected in their eigenvalues when comparing them to those of the remaining canonical functions. Whereas the first canonical function corresponded to a medium canonical correlation of $R_{C_1} = 0.44$ ($R^2_{C_1} = 0.20$), the second related to a medium canonical correlation of $R_{C_2} = 0.39$ ($R^2_{C_2} = 0.15$). The remaining three canonical functions explained less than 10% of the variance, which is usually regarded to be the threshold of relevance [87].

Table 4. Results of the dimension reduction analysis.

Canonical Function	R_C	Eigenvalue	*F*-Test	*p*
1	0.44	0.24	$F(35,797.48) = 2.82$	<0.001
2	0.39	0.18	$F(24,664.04) = 2.25$	<0.001
3	0.22	0.05	$F(15,527.67) = 1.37$	0.16
4	0.19	0.04	$F(8384) = 1.34$	0.22
5	0.14	0.02	$F(3193) = 1.25$	0.29

Annotation. R_C = canonical correlation.

To clarify the crucial question about the contribution of each variable of the two sets for these two canonical functions (i.e., the relationships between a set's variables and canonical variates), different parameters can be used (see Table 5).

Table 5. Standardized weights, structure coefficients, and communalities of the CCA set variables.

Construct(s)	Variable	h^2	Canonical Function 1 $R_{C_1} = 0.44$ $R^2_{C_1} = 0.20$		Canonical Function 2 $R_{C_2} = 0.39$ $R^2_{C_2} = 0.15$	
			β	r_s	β	r_s
Big Five personality traits	Neuroticism	0.12	−0.14	−0.28	−0.46	−0.20
	Extraversion	0.12	−0.07	0.10	−0.21	−0.34
	Openness	0.56	0.74	0.71	0.24	0.23
	Agreeableness	0.57	−0.22	−0.08	−0.64	−0.75
	Conscientiousness	0.73	0.67	0.63	−0.52	−0.57
Self-concept of professional knowledge, including digitalization-related skills	TK	0.73	0.19	0.43	1.05	0.74
	CK	0.96	0.80	0.96	−0.49	−0.21
	PK	0.29	−0.05	0.42	−0.31	−0.33
	PCK	0.46	0.34	0.68	0.55	0.01
	TCK	0.17	0.05	0.41	−0.11	0.06
	TPK	0.27	−0.06	0.52	−0.28	−0.07
	TPACK	0.30	−0.09	0.55	−0.06	−0.03

Annotation. R_C = canonical correlation; R^2_C = explained variance by canonical correlation; h^2 = communality; β = standardized canonical weight; r_s = canonical structure coefficient; TK = technological knowledge; CK = content knowledge; PK = pedagogical knowledge; PCK = pedagogical content knowledge; TCK = technological content knowledge; TPK = technological pedagogical knowledge; TPACK = technological pedagogical content knowledge.

Table 5 shows that for each of the two sets of variables there is a unique set of standardized canonical weights β_{ij} per canonical function, i.e., for each pair of variates (see equations below Table 1). As we only considered the first two (statistically significant) canonical functions (see Table 4), we accordingly needed to interpret two sets of canonical weights β_{ij} per set of variables. Basically, these canonical weights β_{ij} reflect the individual contributions of a set's variables to a respective canonical variate. However, canonical weights are influenced by interrelations between the variables of a set [97]. In contrast, canonical structure coefficients r_s are independent of such interrelations between the variables of a set. The structure coefficient r_s represents the loading of a set's variable on its canonical variate and is regarded to be relevant in cases of $r_s \geq |0.32|$ since above this value the explained variance (r_s^2) between variable and variate exceeds 10% [105]. To interpret the variates meaningfully, both the loadings r_s and the canonical weights β_{ij} should be considered. However, it is important to note that their values can relate to each other concurrently or inversely, i.e., r_s and β_{ij} can either be both high or both low, or high loadings r_s can correspond to low canonical weights β_{ij} and vice versa. The latter case would be a reason to reexamine the data more closely for either collinearity or suppression effects (for a deeper discussion, see [96]).

A closer look at the canonical weights β_{ij} of the Big Five personality traits (set *X*) regarding the first canonical function revealed that openness to experience ($\beta_{x_{3.1}} = 0.74$)

and conscientiousness ($\beta_{x_{5.1}} = 0.67$) have been assigned by far the largest values. In contrast to this, the contributions of the other three set variables (neuroticism, extraversion, agreeableness) to their variate X_1^* were considerably smaller. This pattern is entirely supported by the corresponding loadings r_s of which only those for openness to experience ($r_{s_{x_{3.1}}} = 0.71$) and conscientiousness ($r_{s_{x_{5.1}}} = 0.63$) reached values of relevant magnitude. In addition, a closer look at the set of variables of the TPACK model (set Y) revealed that CK ($\beta_{y_{2.1}} = 0.80$) has been assigned by far the largest canonical weight in the first canonical function, followed by PCK, whose weight $\beta_{y_{4.1}} = 0.34$ was considerably smaller, whereas even smaller contributions to Y_1^* have been reached by the other five set variables (TK, PK, TCK, TPK, TPACK). However, this pattern is only partially supported by the corresponding loadings r_s. While those for CK ($r_{s_{y_{2.1}}} = 0.96$) and PCK ($r_{s_{y_{4.1}}} = 0.68$) were the largest, the loadings r_s of all other set variables (TK, PK, TCK, TPK, TPACK) also reached values of relevant magnitude even though their canonical weights β_{ij} were comparatively marginal.

Regarding the second canonical function, a closer examination of the canonical weights β_{ij} of set X revealed that agreeableness ($\beta_{x_{4.2}} = -0.64$) and conscientiousness ($\beta_{x_{5.2}} = -0.52$) have been assigned the largest values, which was also corresponding to their loadings ($r_{s_{x_{4.2}}} = -0.75$ and $r_{s_{x_{5.2}}} = -0.57$). In contrast to this, the contributions of the two set variables extraversion and openness to experience to their variate X_2^* were much smaller, which is almost congruent with their loadings r_s as well. However, in case of neuroticism, an inhomogeneous pattern resulted, including a comparatively large canonical weight of $\beta_{x_{1.2}} = -0.46$, which inversely related to a considerably smaller loading of $r_{s_{x_{1.2}}} = -0.20$. Furthermore, a closer look at the set of variables of set Y revealed that TK ($\beta_{y_{1.2}} = 1.05$) was assigned by far the largest weight, whereas PCK ($\beta_{y_{4.2}} = 0.55$) and CK ($\beta_{y_{2.2}} = -0.49$) reached values only about half as large, and PK ($\beta_{y_{2.2}} = -0.31$) a value less than one third as large. Even smaller contributions to Y_2^* have been reached by the other three set variables (TCK, TPK, TPACK). Similar to the first canonical function, this β_{ij} pattern of set Y is again only partially supported by the corresponding loadings r_s. While the loading of TK ($r_{s_{y_{1.2}}} = 0.74$) was the largest and therefore corresponded to $\beta_{y_{1.2}}$, those for PCK ($r_{s_{y_{4.2}}} = 0.01$) and CK ($r_{s_{y_{2.2}}} = -0.21$) did not conform to their comparably large canonical weights $\beta_{y_{4.2}}$ and $\beta_{y_{2.2}}$. However, the loadings r_s of the remaining variables (PK, TCK, TPK, TPACK) were approximately in line with their corresponding canonical weights β_{ij}.

Beyond that, in the framework of CCA, the squared canonical structure coefficients r_s^2 can be used to calculate the adequacy index (AI), which indicates how accurate a canonical variate represents its constitutive set of variables [97]. For this purpose, the squared loadings per statistically significant canonical function and per each set of variables are summed up and these sums are then divided by the number of variables in the respective set. Thus, the AI corresponds to the proportion of shared variance between a variate and a related set of variables per canonical function ($0 \leq AI \leq 1.0$). Regarding the set of variables of the Big Five personality traits (set X), the AIs were $AI_{X_1^*} = 0.20$ (first canonical function) and $AI_{X_2^*} = 0.22$ (second canonical function), respectively. The AIs concerning the set of variables of the TPACK model (set Y) were $AI_{Y_1^*} = 0.35$ (first canonical function) and $AI_{Y_2^*} = 0.10$ (second canonical function), respectively.

Finally, the communality h^2 must be considered when interpreting CCA results. h^2 is the sum of the squared structure coefficients r_s^2 of a set's variable across the canonical functions considered. Thus, h^2 represents the overall proportion of a set's variable's variance that is associated with the statistically significant canonical functions [97]. Regarding the set of variables of the Big Five personality traits (set X), the largest communality value resulted for conscientiousness ($h_{x_5}^2 = 0.73$), followed by agreeableness ($h_{x_4}^2 = 0.57$) and openness to experience ($h_{x_3}^2 = 0.56$). In contrast, the two remaining variables of this set, neuroticism, and extraversion, either reached comparably marginal values of $h^2 = 0.12$. Furthermore, a closer look at the set of variables of the TPACK model (set Y) revealed that the largest communality resulted for CK ($h_{y_2}^2 = 0.96$), followed by TK ($h_{y_1}^2 = 0.73$) and, at some distance, PCK ($h_{y_4}^2 = 0.46$). Regarding the four remaining variables of this set, TCK reached by

far the smallest communality of = 0.17, whereas PK, TPK, and TPACK each related to a communality of $h^2 \sim 0.30$.

The path model in Figure 2 gives a graphical overview of the central results of the canonical solution, including the canonical correlations of the two statistically significant canonical functions as well as the set variables' loadings on their respective variates.

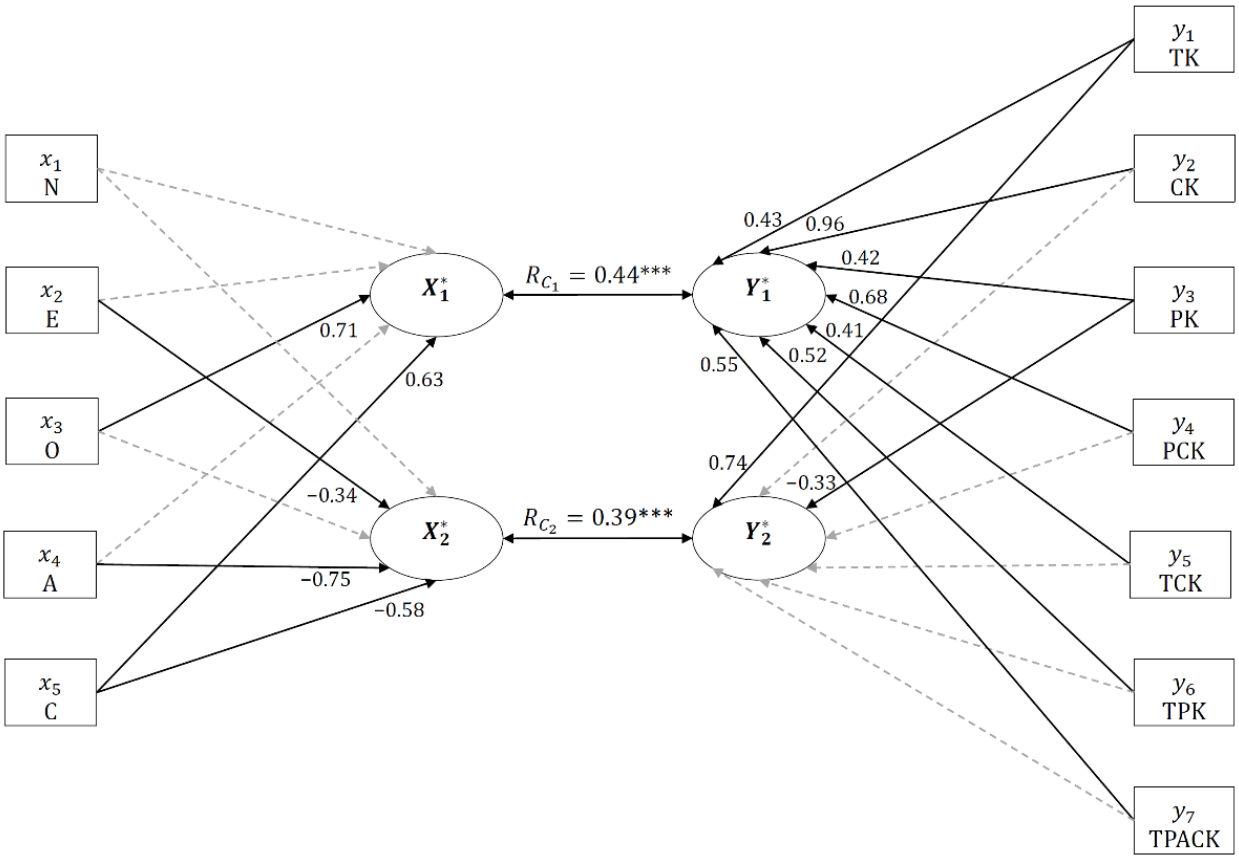


Figure 2. Path model of the canonical correlations R_{c_1} and R_{c_2} as well as the structure coefficients r_s of the NEO-FFI and TPACK sets' variables. *Annotation.* N = neuroticism; E = extraversion; O = openness to experience; A = agreeableness; C = conscientiousness; TK = technological knowledge; CK = content knowledge; PK = pedagogical knowledge; PCK = pedagogical content knowledge; TCK = technological content knowledge; TPK = technological pedagogical knowledge; TPACK = technological pedagogical content knowledge; small loadings (< 0.30) are not represented numerically but by grey dashed arrows; X^* = canonical variate of set X (Big Five personality traits); Y^* = canonical variate of set Y (self-concept of professional knowledge, including digitalization-related skills); R_C = canonical correlation; *** $p < 0.001$.

4. Discussion

The starting point of our study were several organizational psychological studies on the relationships between innovativeness and personality traits in professional contexts that identified the Big Five factor of openness to experience to be particularly influential on employees' innovative behavior [62,64–69]. Against this background, our study aimed at exploring whether comparable results can also be found in the educational context of university teacher training. Since the field of digital teaching and learning is regarded paradigmatic for the construct of innovation in education [70–73], we, therefore, analyzed the relationships between the Big Five personality traits and pre-service teachers' self-concept of professional knowledge, including digitalization-related skills. Our CCA model showed that, first and foremost, the three Big Five variables openness to experience, agreeableness, and conscientiousness relate to the four TPACK variables TK, CK, PK, and

PCK, whereas the actual digitalization-related TPACK domains (TCK, TPK, TPACK) were not sufficiently (i.e., distinctly enough) reflected by our canonical solution (see Section 3.2).

When considering the canonical weights and loadings of the first canonical function (see Table 5), it becomes apparent that the relationship between the two variates X_1^* and Y_1^* is decisively determined by the variables openness to experience and conscientiousness of the Big Five set as well as CK and PCK from the TPACK set. The communalities also show these four variables make the most important contributions to their respective variates of the first canonical function, while all other variables in fact act marginally. Considering the positive algebraic signs in each case, this means that higher values for openness to experience and conscientiousness go hand in hand with higher levels of CK and PCK. However, the other five TPACK variables (TK, PK, TCK, TPK, TPACK) also load comparatively high on their variate Y_1^*. Nonetheless, the fact that they each reach rather small weights at the same time suggests their contributions to Y_1^* to be overlapping with those of other TPACK variables (although they share much variance with Y_1^*) [96,106]. Thus, although we have not seen any evidence of this prior to CCA, some collinearity seems to be present among the TPACK variables. A plausible explanation for this may be that the pre-service teachers did not (or could not) sufficiently differentiate between the self-assessment items within the TPACK questionnaire. The actual digitalization-related teaching skills of the TPACK model (TCK, TPK, TPACK) seem instead to be caught up in PCK in the first canonical function. This is also suggested by the pattern of bivariate correlations, as the digitalization-related teaching skills (TCK, TPK, TPACK) are more closely related to PCK than to CK (see Table 3). This, in turn, can be explained in two ways: Either the digitalization-related teaching skills of students who achieve high values on openness to experience and conscientiousness are understood as a matter of course in teaching (i.e., these skills are considered to be PCK-inherent and thus not differentiated from this domain of knowledge) or these students are not yet able to reliably assess their own competences in this regard due to a lack of practical teaching experience [107]. Nevertheless, despite some degree of collinearity of the TPACK variables in the first canonical function which may reduce the individual variables' impacts on their variate, it must be noted that *all* TPACK variables are clearly positively associated with the Big Five variables of openness to experience and conscientiousness (see Figure 2).

When considering the canonical weights of the second canonical function, the variables of agreeableness and conscientiousness of the Big Five set as well as TK and PK of the TPACK set turn out to be particularly relevant for the relationship between the variates X_2^* and Y_2^*. Overall, these results again correspond to the loadings and the communalities. Taking into account the algebraic signs, this means that higher values on agreeableness and conscientiousness go hand in hand with higher levels of PK but lower levels of TK at the same time. Conversely, the latter aspect corresponds to the interesting result that a dominant affinity for technology seems to be associable with the risk of lower values on personality traits that are regarded to be pedagogically and didactically relevant. Furthermore, the data on all other variables of the two sets (neuroticism, extraversion, openness to experience [set X] as well as CK, PCK, TCK, TPK, TPACK [set Y]) prove to be inconsistent when looking at their canonical weights and loadings, so a clear interpretation of their contribution in building the two variates fails.

This latter finding is also reflected by the adequacy indices of both canonical functions, indicating that a maximum of only 35% of the variable sets are represented in the variates across the two functions. Critically speaking, this means that our canonical model could also get along with fewer variables, including TK, CK, PK, and PCK on the one hand as well as openness to experience, agreeableness, and conscientiousness on the other hand. In this respect, we assume that the validity of the model could be significantly improved by addressing our study's limitations in future studies (see Section 4.1).

4.1. Limitations

As explained in the previous section, a certain degree of multicollinearity, particularly among the TPACK variables, limits the interpretability of our results. Against the background of the explanations for these intercorrelations (mistaking digitalization-related teaching skills as an inherent facet of PCK or a lack of practical experience, which is needed for reliable assessments), it would be worth considering whether to either select a sample of aspiring teachers with more practical experience (e.g., trainee teachers) or, alternatively, to assess the dimensions of the TPACK model using objective performance tests instead of a self-assessment. Both approaches could contribute to a more distinct reflection of the digitalization-related domains of the TPACK model in the canonical variates.

The variables considered in our CCA did not meet the assumption of multivariate normal distribution. Although the univariate deviations in this regard were not severe, the accuracy of significance testing could probably be improved if the assumption of multivariate normal distribution was met optimally, especially when considering the just adequate sample size (n = 201) and the background of an exploratory study (see Sections 1.4 and 2.2). Multivariate normal distribution could possibly be achieved by increasing the number of subjects, which would have the advantage that the accuracy of the canonical solution as a whole (not just that of significance testing) could be improved as well [94,95]. However, against the background of our exploratory research interest, we consider the heuristic value of our canonical model to be helpful and important for future research (see Section 4.2).

4.2. Practical Implications and Prospects for Future Research

Although the actual digitalization-related teaching skills of the TPACK model (TCK, TPK, TPACK) were not sufficiently reflected by our overall CCA model (since they are presumably caught up in the domain of PCK), our results allow for discussing some practical implications regarding pre-service teachers' innovativeness. According to the existing public recommendations [10,32,33], it is of course indisputable that (aspiring) teachers should, first of all, acquire in-depth theoretical knowledge and practical skills to successfully deal with digital teaching and learning formats. However, in order to support the success of such educational initiatives, our results suggest that it could be helpful to also address pre-service teachers' personality traits in order to qualify them, as it were, for acting as 'agents of change' during their professional careers.

Within our first canonical function, the two personality traits of openness to experience and conscientiousness appear to be significantly related to the overall professional knowledge of our sample of pre-service teachers (see Section 3.2). Since this professional knowledge also includes the specific digitalization-related skills, which in turn are positively associated with the construct of innovativeness [70–73], it can be assumed that the personality trait of conscientiousness may be just as important as the trait of openness to experience when looking at university teacher training. Thus, the results of our study go beyond the consensus of the referred organizational psychological findings, stating openness to experience to be the key factor regarding the innovative behavior of employees in other professional contexts [62]. However, the finding that conscientiousness turned out to be equally important in our study seems plausible, since, within the scope of public debates regarding the Education in the Digital World strategy [10] or the European DigCompEdu framework [32], most pre-service teachers may be aware of the fact that teachers are meanwhile *expected* to be skilled in successfully using technology in the classroom. As conscientiousness includes facets such as a sense of duty and a need for achievement [44,45], particularly conscientious pre-service teachers may therefore more likely work hard at successfully acquiring these skills.

Nevertheless, openness to experience also seems to be decisive for such a successful acquisition of skills, but in our sample this trait was significantly less pronounced than conscientiousness (see Table 2). Accordingly, a targeted promotion of openness to experience could be a crucial factor in supporting the development of pre-service teachers' professional knowledge, including digitalization-related skills. Meanwhile, different studies in various

fields could already show that a stable change toward more openness to experiences can be achieved in a comparatively short time (a few weeks) and by different approaches. For example, cognitive training can lead to significantly more openness to experience (i.e., cognitive flexibility in choosing different options for action), especially in older people [108]. Besides, smartphone-based coaching offers have also proven to be effective in increasing the facet of openness to action in younger people [109]. A purposeful integration of such effective elements into university teacher training could therefore be a possible starting point to promote pre-service teachers' innovativeness.

However, since our results are not robust enough to derive far-reaching recommendations for action (see Section 4.1), we encourage other educational researchers to conduct further studies to clarify the existing relationships between the constructs of teacher personality, professional knowledge, and innovativeness. In this connection, it must be noted that other findings may be found for teaching subjects other than biology, and even more so for courses of study other than teacher training. For example, in her comprehensive review, Vedel [110] reported substantial pre-existing and gender-independent personality differences across students of different academic majors, with the largest effects found for the Big Five trait of openness to experience. In another study, Hartmann and Ertl [111] showed that teacher candidates were significantly more extraverted than students who studied the same major but who did not intend to become teachers. Moreover, in a comparison between pre-service teachers studying a STEM or non-STEM subject they additionally found differences in varying directions depending on which specific STEM and non-STEM majors are compared. Therefore, it seems necessary to consider the students' fields of study in future research. Furthermore, such future studies may also consider other than digitalization-related constructs of innovation within the educational context, such as inclusive teaching and learning [112] or the successful integration of current environmental or health-related issues in school [113]. Their results could at best help to drive long-lasting change in education toward more innovation and sustainable progress.

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Institutional Review Board Statement: In accordance with local legislation and institutional requirements, an ethics board approval was not required for this study on human participants. In Germany, as stated by the German Research Foundation (DFG) [114], the present survey did not require the approval of an ethics committee because the research did not pose any threats or risks to the respondents, and it was not associated with high physical or emotional stress. Nevertheless, it is understood, that we strictly followed all ethical guidelines as well as the Declaration of Helsinki [115,116]. Before taking part in our survey, all participants were informed about its objectives, absolute voluntariness of participation, possibility of dropping out of participation at any time, guaranteed protection of data privacy (collection of only anonymized data), possibility of requesting data cancelation at any time, no-risk character of study participation, and contact information in case of any questions or problems. Furthermore, the respondents were explicitly given the opportunity to leave answers blank. Data storage meets current European data protection regulations [117].

Informed Consent Statement: All participants declared their informed consent before participating in our survey.

Data Availability Statement: The data presented in this study are available on request from the corresponding author (V.D.E.W.).

Conflicts of Interest: The authors declare no conflict of interest.

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