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The Development of Prospective Primary School Science Teachers' TPaCK Fostered by Innovative Science-Teacher Education

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Abstract: The EEdnaS study "Development and testing of digitally enriched science-related subject matter teaching in digital teaching-learning labs and university classrooms" aims to promote the professional competencies of prospective teachers that are needed for teaching science content in a world shaped by digitalization. To achieve this goal, university teaching units (seminars) that directly address cognitive components of a teacher's professional competencies, which are important to teaching science content in primary school education, were developed. In addition, prospective teachers were asked to plan, implement, and evaluate primary school science education with a particular focus on digitization, as well as sharing the developed units as open-educational resources. This article reports on the impact of the first part of the seminar concept, in which the promotion of digitization-related, subject-specific teaching methodology, as well as content-related knowledge (TPaCK) was systematically promoted. In a standardized survey, it could be shown that the prospective teachers demonstrated positive developments, particularly in the components PCK, TCK, TPK, as well as TPaCK, regarding the self-efficacy in cognitive characteristics about one's own ability within the reference frame of self. Furthermore, the development of knowledge, especially in the areas of TK, PCK, TCK, and TPK, could also be determined, but not in relation to TPaCK itself.

Keywords: pre-service teacher education; primary school science-teacher education; TPaCK

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1. Introduction

Not only, but especially, since the COVID-19 pandemic, teachers and their digitalization-related competencies have been in the focus of the social and political public [1]. Nationally and internationally, there is a consensus that teachers should be able to plan lessons considering digital technologies, as well as using them to benefit the learners [2–6]. Nationally and internationally, there is a consensus that digital media not only occur in the classroom/teaching-learning process (use technology); rather, teachers should systematically exploit their potential in relation to teaching and learning in an integrated way [7–10]. Proceeding from current ideas that such professional actions are based on profession-specific competencies that can, in principle, be learned, e.g., [11], this leads to the question of how these digitization-related competencies can be theoretically described and, furthermore, systematically promoted. How prospective teachers acquire digitization-related competencies is hereby a question that is as old as the first personal computers (PCs) themselves. PCs were first installed in schools as early as the end of the 1970s in the U.S. Since the introduction of the first learning programs in the 1980s, demands were voiced that teachers should be able to acquire technical or digitization-related competencies with the help of advanced training courses [12]. However, technical/digital competencies were not demanded as part of teachers' professional knowledge, until the early 2000s [13].

This article focuses on the promotion of these competencies, based on what is currently understood as the digitization-related competencies of (science) teachers. We initially focus on current descriptions of digitization-related competencies (first major paragraph). They contain descriptive requirements for teachers to master or acquire (in the sense of skill descriptions) to successfully conduct their professional duties (e.g., SAMR model and DiKoLAN, https://dikolan.de/us/, accessed on 13 April 2022). This is followed by the presentation of an overview of models that focus on the necessary knowledge (TPaCK, Technological Pedagogical Content Knowledge) as well as skills and abilities of teachers (TDC, Teacher Digital Competency). Some of these models represent essential foundations for institutions of teacher education. Empirical evidence about what characterizes teachers' professional competencies (in science subjects) is based on all these models. The findings on the characteristics of competencies of teachers is elaborated in a further step (second major paragraph)—both in general, as well as with reference to the teaching of science in a primary school. We subsequently discuss, within a third major paragraph, starting points for the promotion of these competencies that have already been theoretically described. The presented theoretical analyses are used to derive our innovative program for promoting digitization-related competencies for teaching science in an elementary school. Additionally, a research project, which focuses on the development of these competencies among prospective teachers, was initiated. The results provide insights into how constituent skills and abilities of prospective teachers have modified over the course of a semester, while undergoing the innovative intervention. Based on these results, tentative conclusions can be drawn for university teaching designs. They address the promotion of these competencies for prospective elementary teachers related to science teaching and learning in an elementary school.

2. Digitization-Related Competencies for the Teaching and Learning of Science Teachers

2.1. What Should Teachers Be Able to Do?

Digitization-related competencies refer to general, overarching, activity-related competencies in an increasingly digitized world. To date, many models exist that describe these competencies, thus functioning to support the education of prospective as well as practicing teachers. A systematic analysis of digitization-related requirements for teachers was, for example, provided by Guzmann and Nussbaum with an international document analysis [6]. They identified the following six competency domains that should also support areas of teacher education processes:

- Instrumental/technological domain;
- Pedagogical/curricular domain;
- Didactic/methodological domain;
- Evaluative/investigative domain;
- Communicational/relational domain;
- Personal/attitudinal domain.

Essentially, the SAMR (substitution, augmentation, modification, redefinition) model (Figure 1) is a descriptive framework for ways to evaluate, select, and use digital media on different hierarchical levels [14]. This guide can be utilized by practicing and prospective teachers and is empirically well supported, e.g., [15,16].

In Germany, digitization-related competencies of teachers are divided into the following five areas (political position paper, not mandatory). They specifically describe areas of action in which teachers should acquire or possess competencies:

- Ability to communicate successfully;
- Ability to find creative solutions;
- Ability to act competently;
- Ability to think critically;
- Ability to work together [17] (p. 8).

In addition, there is another prominent model in Germany that establishes and differentiates further digitization-related areas of competence that are relevant for the education of prospective teachers: planning, conducting, evaluating, and sharing of lessons (Innovation Program: "Digital Campus Bavaria", [18]).

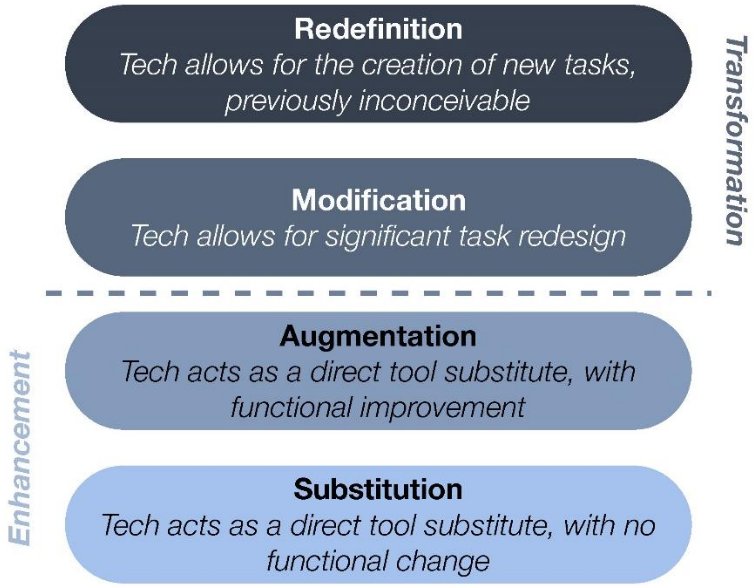

Figure 1. The SAMR model. Available online: http://www.hippasus.com/rrpweblog/archives/2011/12/08/BriefIntroTPCKSAMR.pdf (accessed on 13 April 2022) under CC BY-NC-SA 3.0 license.

These highly generic descriptions, which are formulated in a very general and interdisciplinary way, are to be differentiated and enriched regarding the individual subjects, their specifics, and the respective types of schools, i.e., also with regard to science teaching in an elementary school. An indication of digitalization-related competencies for teaching science is depicted in the DiKoLAN model. On the one hand, it includes more general competencies, such as documentation and presentation communication/collaboration, as well as information search and evaluation. On the other hand, the model also implies more subject-specific competencies, such as data acquisition, data processing, as well as simulation and modeling. All models mentioned here describe competencies in terms of requirements that can be mastered in actual professional life.

2.2. Which Abilities and Skills Constitute These Competencies?

In addition to these models, there is a well-established research paradigm. It deals with the professional competencies of teachers, but also describes the skills and abilities needed for competent action in a way that is more in line with the psychological research on expertise [11,19].

Regarding the professionalization processes of science teachers, an internationally published model was established by Baumert and Kunter within the last decade [11,20]. At its center is the professional action-related competence (the professional knowledge), which is, in particular, divided into the knowledge and skill areas of "Pedagogical Knowledge" (PK), "Content Knowledge" (CK), and "Pedagogical Content Knowledge" (PCK). Regarding the model, the authors emphasize the connection of these knowledge and skill domains with the domains of "Beliefs/Values", "Motivational Orientation", and "Self-Regulatory Skills". To date, it is generally accepted that the responsible use of digital media/technology constitutes the basis for living in a globalized, knowledge-based world (see, e.g., ICT Competency Framework for Teachers, https://en.unesco.org/themes/ict-education/competency-framework-teachers (accessed on 31 March 2022); The OECD Learning Compass 2030, https://www.oecd.org/education/2030-project/contact/OECD_Learning_Compass_2030_Concept_Note_Series.pdf (accessed on 31 March 2022)). The internationally recognized model TPaCK (Figure 2) was published almost simultaneously in 2006. This model interrelates the technological/digital knowledge components to the previously established PCK model in a structured way [21].

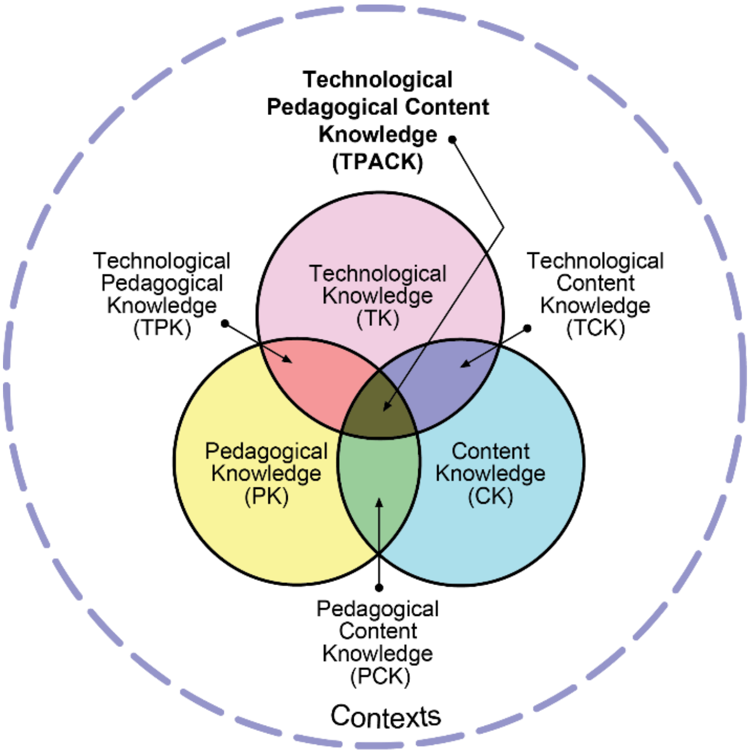

Figure 2. The TPaCK model. Available online: http://tpack.org/ (accessed on 14 March 2022). Reproduced by permission of the publisher, © 2012 by tpack.org.

It established new aspects of professional knowledge: Technical Knowledge (TK), Technical-Content Knowledge (TCK), Technical-Pedagogical Knowledge (TPK), and, as the integration of all knowledge areas, Technical-Pedagogical Content Knowledge (TPaCK). They can be derived from the recently published model, "Digital Competencies for Teaching in Science Education", for which Content Knowledge as well as Technical-Content Knowledge are of particular importance regarding teacher education in science subjects.

In addition to subject knowledge, the importance of profession-specific knowledge, especially teachers' subject-specific teaching, methodology knowledge was shown to be particularly significant for learning progress and motivational goal achievement among students within studies on teaching quality, e.g., [22–25]. These significant learner support variables have also been documented for elementary school science instruction [26]. Information and communication technologies have rapidly evolved since the development of the TPaCK model by Mishra and Köhler in 2006. New factors, "such as cybersafety and managing personal data and online presence, digital citizenship, ethics and judgment, building knowledge from, and collaborating in, online networks and virtual environments" [5] (p. 2455), have become important for the education of children and youths. Based on the work of Jansen et al. (2013) [27], Falloon [5] further developed the teacher digital competency (TDC) model. It now combines the basal digitization-related competencies of teaching (TPaCK) with personal-ethical and personal-professional competencies.

> *"This signals the importance of teacher education students understanding how to integrate into subject-related activities involving learning with, about and through digital technologies, understandings and capabilities aligned with personal-ethical and personal-professional competencies. This integration could occur at planning, pedagogical and practice levels."* [5] (p. 2462)

3. What Do We Know about Teachers' Willingness to Use Digital Media in Schools and Classrooms?

Approaches of teachers regarding the application of digital media in the classroom vary greatly from country to country [28] Until the mid-2010s, studies found that prospective teachers in Germany tended to have a critical, dismissive attitude toward the integration of digital media in schools and classrooms, e.g., [29,30]. Subsequent representative surveys indicated that teachers demanded a greater inclusion of digital media in the first and second phases of teacher training [31]. Meanwhile, there are requirements that digital media must be given greater consideration in all phases of teacher training [32]. It can therefore be concluded that teachers recognize a need for the use as well as the integration of digital media in classrooms. Furthermore, the surveys suggest that the basis for more positive attitudes towards digitization-related actions and objects is presumably more knowledge about the possibilities of digital media in schools and teaching [4] (p. 109). Above all, knowledge about the integration of digital media in teaching-learning settings should be embedded in teacher training. In addition, this knowledge should be directly applicable to internships, as an interview study with preservice early childhood teachers found out [33].

However, elementary school teachers, in particular, are often reluctant to teach science content, which is attributed to limited science subject knowledge as well as limited pedagogical content related to science education [34].

Additionally, a majority of science teachers still evaluates the presence of ICT in schools as something fundamentally new, especially regarding (the integration of) digital media, although the use of ICT only complements, but does not change, the teaching itself [35].

Especially at elementary schools, highly different starting points of in-service teachers are evident [36] regarding the competence and experience with digital media. The International Computer and Information Literacy Survey (ICILS) found that only about a quarter of the teachers surveyed indicated that the use of digital media (for teaching) was part of their training [37]. It states the following about self-assessed competence: "Teachers in Germany are most confident in finding useful teaching materials on the Internet (98.1%). More than three quarters (78.9%) are also confident in preparing lessons that involve the students' use of digital media. However, only about one-third (33.6%) of teachers in Germany dare to work with a learning management system" [37] (p. 18). Furthermore, only about one third of the respondents estimated that digital media has the potential to improve academic performance (international 71.0%, EU 51.5%) (ibid.), although teachers observe a clear advantage in using ICT in order to access safe information sources, as well as the encouragement of personal interests.

The need for school closures and distance learning produced new insights. A survey of 93 teachers at elementary schools in Germany at the beginning of the COVID-19 pandemic showed the following: The majority of schools neither had overall concepts for integrating digital media, nor would digitization have evolved the capabilities of their school during the school closures. Moreover, during this time, teachers were unable to adequately implement learning opportunities due to insufficient technical equipment for students. The learning opportunities initiated in this way through or with digital media were additionally rated as less effective by around 75% of the teachers that were surveyed. In an overview, teachers at elementary schools indicated the lowest levels of further development and the possibility of integrating digital media into learning opportunities during school closures in almost all categories [38].

From this, too, the clear needs for teacher training (1st phase), which particularly pursue the structured stimulation of professional, digitization-related knowledge as well as cognitive competencies (including cognitive convictions), can be derived.

4. What Do We Know about the Ways to Develop and Foster These Competencies?

As numerous studies indicate, professional competencies can, in principle, be learned and fostered, e.g., [39,40]. However, how are teachers' professional competencies developed and which cognitive processes lead to the merging of pedagogical and content knowledge? Theories of professionalization also determine that professional competencies do not solely come about by practicing a profession, but require motivation and deliberate, so-called purposeful practice, as well as feedback and tutoring support from experts [41]. If the synthesis of prior pedagogical knowledge and prior content knowledge is explicitly encouraged, a synthesis of pedagogical and content knowledge can occur. This is framed within the so-called Amalgamation Hypothesis [42]. However, there are indications that teachers' content knowledge alone is not sufficient to develop pedagogical knowledge [43] and that, likewise, advanced content knowledge does not lead to advanced pedagogical knowledge in every case, e.g., [44].

Studies on PCK knowledge domains are available, e.g., the T-KnoX study. According to this study, the promotion of CK is to some extent sufficient to the development of PCK, but an explicit teaching of PCK is significantly more effective [45]. Somewhat smaller effects could be achieved by using an amalgamation, addressing the knowledge domains of CK and PK (ibid.). Further gains in pedagogical knowledge (PK) did not lead to an improvement of pedagogical content knowledge (PCK), but, at the same time, the direct addressing of PCK led to the improvement of PK and CK (ibid.). The T-KnoX study did not, however, consider primary school teachers and, moreover, focused on the content of mathematics, but without the systematic inclusion of ICT.

Accordingly, there is evidence of what characterizes professional competencies of teachers (especially in mathematical and scientific subjects) and how they can be purposefully fostered, e.g., [20,42,46]. Consequently, several studies and initiatives have deduced indications for teacher education with special attention being given to the integration of digital media.

In their study, a team of researchers additionally addressed the research gap of linking digitization-related competencies (knowledge and action) with media pedagogical approaches [47]. They initially reviewed the impact of the strategies described at the micro level of the SQD model on TPaCK development: (1) role models, (2) reflection, (3) lesson design, (4) collaboration, (5) authentic experiences, and (6) feedback (ibid). In a mixed-methods design with survey data from 688 teachers and subsequently 16 telephone interviews, it was found that the consideration of each strategy as well as all strategies together had a significantly high impact on TPaCK development. The impact of teacher educators as role models was a particularly important motivator for improving student teachers' TPaCK.

The authors therefore concluded that extensive professional development of teacher trainers in the individual disciplines regarding TPaCK is necessary. Thus, digitization-related competencies of teachers are characterized by teachers' ability to select, use, reflect, and share the use of digital media in relation to the effectiveness of the content learning experience. In other words, knowledge (in the sense of the TPaCK model), which is supplemented by the cognitive (self, teaching-learning context) and motivational (subject and teaching enthusiasm) characteristics [48] (in connection with one's own media competence), could have an effect on the media-related teaching competencies (planning, realization, evaluation, and sharing [18] (p. 35)), and therefore on teaching quality (components of teaching quality according to [49]).

Comprehensive anthologies, such as the "International Handbook of Science Education", the "International Handbook of Teacher Education", "Handbook of Research on Science Education" or in the German-speaking area "Fachdidaktik Naturwissenschaft-1. -9. Schuljahr", point out the challenges of teaching and learning in science. Basic contents for a professional teacher education of science teachers can be derived from these anthologies/works (keywords: conceptual change, subject linguistics, models, and nature of science). Nowadays, the consideration of digital possibilities for university teaching and instruction is still neglected [50] or rarely specifically promoted by teacher educators in their teacher education [39]. Other studies (summary of [51] (p. 10)) show that, compared to other student groups, teacher trainees in particular have a low level of ICT literacy and often do not develop their digitalization-related competencies during their studies [4,52]. These deficits persist during the teacher traineeship [31]. This fact has been clearly demonstrated among prospective teachers, especially among those without STEM studies [52]. This is due to the special media habitus of these students, which is characterized by a comparatively large distance when compared to digital media [53]. This is based on the media-use patterns of their parents, which are particularly critical and characterized by a strong regiment of use [ibid]. These fragmentary findings suggest that teaching-related competencies based on CK and ICT are not well developed in student teachers that aim to teach science at the elementary school level and need to be fostered. In Germany, there are increasing social and political demands to promote the digitization of schools and teaching (DigComP; KMK; "Digitalpakt Schule"). Although there are well-founded indications of how university subject-specific teaching methodology seminars for prospective teachers should be designed to promote pedagogical content knowledge (PCK) (see, e.g., [54]), there are, however, few studies showing us how to learn the use of ICT in subject-specific teacher education. Tondeur et al. (2012/2019) developed the model of synthesis of qualitative evidence (SQD) and conducted a study to verify whether this model explicitly promotes the domains of the TPaCK model (Figure 2) [47,55]. Study results that are partly contradictory can be found (e.g., [56,57]) regarding the question of whether knowledge areas in teacher education should be addressed in a networked or sequential (amalgamation) manner.

Kleickmann and Hardy outlined the knowledge development of prospective teachers as a complex construct of horizontal (subject-specific, subject-specific teaching methodology, and educational science), vertical (cooperation of the phases of teacher education), as well as collegial networking (cooperation of the teachers) of the professional knowledge areas [58]. Therefore, the respective university locations are faced with the challenge of individually designing the curriculum of their teacher-training program as optimally as possible for the acquisition of competencies by their prospective teachers. However, future teachers would definitely need to be explicitly supported to link areas of TPaCK in order to effectively plan the integration of technology in teaching [59,60].

5. Innovative University Teaching for the Fostering of Digitization-Related Skills and Abilities Concerning Science Teaching and Learning: The EEdnaS Project

The deficit in teacher education has been addressed by the funding guideline "Quality Offensive Teacher Education" (funding priority "Digitization in Teacher Education") of the German Federal Ministry of Education and Research (BMBF) since 2018. As a result, individual and collaborative projects at various university locations in Germany are increasingly investigating questions about how teacher education regarding digitization-related competencies of prospective teachers must be improved to optimize the digitization of schools and teaching in the medium to long terms (https://www.qualitaetsoffensive-lehrerbildung.de/lehrerbildung/de/programm/grundlagen/grundlagen (accessed on 13 April 2022)).

As a sub-project of "PraxisdigitaliS" ("Praxis digital gestalten in Sachsen"), this challenge is specifically addressed by the project "Development and Testing of Digitally Enriched, Science-Related Teaching in University Classrooms and Teaching-Learning Laboratories" (EEdnaS). It addressed the subject of the subject-specific teaching methodology education of student teachers regarding science learning at the primary school level.

Regarding the previously established Technological Pedagogical and Content Knowledge (TPACK) of (prospective) teachers, the aim of the EEdnaS project is to interlock the fostering of professional competencies with the development, testing, research, and distribution of digital learning environments to improve the teaching quality of science lessons at the primary school level. In relation to the different phases of teacher education (three phases in Germany), the digitization of university teaching, school, and teaching always depicts an area of conflict between the development and fostering of knowledge and attitudes (competencies) as well as the equipment of the respective educational institution (e.g., mobile devices, stability/coverage of WLAN), administrative requirements (e.g., data protection, focus of the respective school offices and school administrations), and competencies of the teachers at the universities. To reduce this tension, subject-specific teaching methodology research should map out fundamentally authentic derivations (so-called conditions for success) for professional practice. Involving the included participants can be achieved with the research-theoretical approach of design research (DR), in which they are able to draw practical conditions of success from the design of subject didactic seminars in teacher education.

We derived from the previous execution that our study needs to develop interventions for teacher education, which consider the following areas:

(1) Professional knowledge domains (TPaCK) are always addressed in an integrated or amalgamated manner.
(2) Learning opportunities for student teachers include elements of reflection on their own actions, their own lesson design, collaborative work in teams, testing of planned lessons in a laboratory setting, and structured feedback.
(3) Additionally, teaching instructors will need to be trained further as role models, as well as act as role models based on the previously mentioned elements.

6. Research Question and Innovation Potential

The starting point for the study described in the present work is a central problem of practice. As outlined above, the challenges of teacher education lie in the respective subject disciplines: How do professional competencies for teaching subject content with particular attention to digital media/technologies develop in prospective teachers? There are robust theoretical constructs and empirical research that describe the competencies that teachers should acquire, followed by initial indications of how teaching-learning opportunities should be designed in the different phases of teacher education. In addition, theoretical constructs and empirical research on how elementary school science instruction should be designed exist as well (for a comprehensive and up-to-date overview, see, e.g., [61–63]). In this context, the use of digital media has hardly been taken into account as it has been systematically considered in the promotion of the development of professional competencies of prospective teachers related to science education and the corresponding research in this field. Moreover, teaching concepts for science learning at elementary school have sufficiently considered the integration of digital media theoretically, researched it empirically, and integrated it conceptually based on this. The European Commission took up this deficit and published the "Digital Education Action Plan (2021–2027)". Nevertheless, all parties involved in the teaching process are faced with great challenges. At the University of Leipzig, teacher training in the subject-specific teaching methodology of science teaching at the primary school level is therefore planned and implemented in a way that allows students to be systematically supported in their development of TPaCK and in practicing their digitalization-related skills. We assume that the treatment briefly described in the section "The first project cycle", will lead to changes in the students' knowledge and beliefs (as cognitive characteristics of teachers' professional competence).

7. Sample/Participants

Students at elementary school and special education teaching formed the target population of this study and its investigative intervention to support the development of professional competencies among prospective teachers. They were enrolled as regular students at the University of Leipzig in the summer term of 2021. In general, the students were in their 6th semester and formed a total of 333 participants. In addition, students had completed almost all of their internships at this point (this included three 4-week internships as well as two internships where students taught two lessons one day a week for 15 weeks each). Depending on their course of study, they were attending two or three Natural and Social Science Teaching Modules at the time of their participation in the intervention. Among these courses was at least one module titled "Introduction to the Subject-Specific and Subject-Specific Didactic Foundations in Relation to General Science" (CK and PCK, Fundamentals), as well as one module focusing on in-depth subject-specific didactic content (PCK). The students of the elementary school teacher-training program also participated in one in-depth subject-specific science and subject-specific didactics module (CK and PCK). Furthermore, all students attended at least six modules with a pedagogical focus (PK). Regarding the researched seminar, the students were offered a selection of 16 different seminars in the study program, from which they could choose. The main reasons for their participation were personal interest on the one hand, and reasons of study organization (matching of class/semester schedule) on the other hand. A total of four seminars with 25 places each were offered for the focused topic in the summer term of 2021 (total n in the courses = 65). These courses were titled "Development, testing, and evaluation of digitized learning environments/learning tasks in science education". Participation was part of the compulsory graduation curriculum for all participants of the study. The choice of seminar was, however, voluntary. Attendance was not compulsory, but an (ungraded) examination had to be submitted and passed at the end of the semester. Due to research ethics, the performance records were not used as data sources for this research. From this overall sample, 24 students participated in the first two survey periods of the accompanying research. Thus, this was a non-representative opportunity sample [29] (n = 24) that occurred at two measurement points (pretest and post-test) relating to the development of TPaCK (measuring point 1 (MP1) to measuring point 2 (MP2)). Nearly two-thirds of the seminar participants were studying to become teachers at elementary schools, and one-third were studying to become teachers in special needs education. During the survey period, three quarters of the interviewees were between the ages of 21 and 23 years (92% female).

8. The First Project Cycle/Intervention and Instruments

The EEdnaS study, in which the development of professional competencies of prospective teachers is outlined, with special regard to the TPaCK, is designed as design research [64] in two cycles. This allows for authentic research and scientific modeling in the context of teacher education. The study included more explanatory (hypothesis-guided) as well as more exploratory (hypothesis-generating) parts [65]. Each cycle was inherently designed in a mixed-methods design [66], combining quantitative and qualitative research methods. Both research approaches and methods were simultaneously implemented. The integration of quantitative and qualitative data already occurred during data collection by incorporating open-ended questions without response specifications into the otherwise closed-ended survey questionnaire [67]. The interventions focused on the development of aspects of the TPaCK model related, in particular, to knowledge and beliefs. Resulting from both cycles, the conditions for success were derived as to how seminars in teacher education must be designed to promote TPaCK with reference to science teaching and learning in a primary school. Thus, a study design was developed, which aimed to develop a concept for subject-specific teaching methodology university teaching (science teaching and learning in an elementary school) in two successive cycles. This paper refers to the results of the development of TPaCK among students from Design Phase One (summer term 2021). The ethics committee of the University of Leipzig approved the study on 14 April 2021.

With the help of a pilot run (winter term of 2020/2021), the learning object was specified and structured within the EEdnaS project, and a design was (further) developed.

In order to support the students in building their professional knowledge and beliefs, the first five seminar sessions were set under different foci based on the TPaCK model and the results of the T-KnoX study [45]. Thus, common to all seminars was the degree of interconnectedness, and the depth of aspects of the TPaCK model varied. Individual aspects of the TPaCK were either addressed in an amalgamated, integrated, or in-depth manner. In the first design-experiment cycle, the research interest focused on the possibilities of how students' knowledge and beliefs change over the course of attending one of these seminars. Students of primary school science education therefore received structured and tailored content on the knowledge areas of TPaCK in the first five events, whilst considering the subject didactics of primary school science education (focus on science) and the specific content reference (primary school-relevant content of floating and sinking (displacement, buoyancy, and density)).

The tasks in the seminar were hereby competence-oriented and exemplary. The instructors' intention was for the students to have good learning opportunities themselves, while acting as role models for setting good tasks and using digital media themselves. Students were, for example, asked to create their own explanatory videos, to present complex content to their fellow students using digital presentation media (some of which they had chosen themselves), to post assignments for elementary school students on suitable learning management platforms, as well as to justify their designs. To support CK construction, experiments on the content area of floating and sinking at both pupil and student levels were conducted and reflected (depending on the depth and selection of the knowledge area to be addressed from the TPaCK model). The knowledge area TCK was thus explicitly promoted by introducing functions of digital tools relevant for elementary schools (without content reference), which were to be elaborated and presented by the prospective teachers. If the combined knowledge area TCK was subsequently promoted, then, for example, digital devices for measuring values (force sensors) were presented and the usability of experiments in the content area swimming and sinking was linked to it. For an overview of the seminar concept, see Table 1.

Table 1. Overview of the seminar concept.

Project Phase 1	Project Phase 2	Project Phase 3
5 seminar units of 135 min each	6 seminar units of 135 min each	4 seminar units of 135 min each
Fostering of professional knowledge: TK, PK, CK, PCK, TCK, TPK, TPaCK	Development of the project and lesson planning by students; realization of the project with one 3rd class per seminar group	Follow-up of the project days (including analysis of classroom videos); processing of the materials as OER (sharing)

In this article, the second phase of the first design experiment remains unconsidered: Within small groups, students (collaboratively) planned a teaching-learning project for a 3rd-grade class on a self-selected topic of the elementary school-relevant content floating and sinking (displacement, buoyancy, and density). They were hereby able to draw on comprehensive lesson plans (see KiNT boxes from Westermann-Verlag [68]). However, these lessons should be replanned or supplemented according to the current knowledge of the use of digital media in (primary school) lessons, as well as conducted, evaluated, and shared.

9. Materials and Methods: Intervention Programs

Using a comprehensive measuring instrument, the interventions of the design phases were analyzed at three measuring points each: before the beginning of the content work in the seminar (pre), after the detailed content work (inter-median), and after the end of the seminar (post).

Among other things, the survey instrument (main cycle in the summer term of 2021) included 9 scales on the cognitive trait conviction in the reference system self, related to the beliefs about one's own abilities (Table 2). Therefore, 8 standardized scales related to the prospective teachers' self-efficacy of their abilities in relation to TK, CK, PK, PCK, TCK, TPK, and TPaCK (general teaching at elementary school and explicit science teaching at elementary school) (following the work of [18,69,70]), and a scale on the self-efficacy of being able to explain basic technical functions to children in a child-friendly manner (e.g., all closed scales were measured with a 5- or 7-point Likert scale.

The Cronbach's α test resulted in acceptable-to-good values [71] (related to MP1, n = 24):

Four questions on prospective teachers' cognitive attribute knowledge (explicit content of floating and sinking: buoyancy, displacement, and density) were added and qualitatively evaluated. For example, they were asked: "Describe in bullet points: how would you use digital media to help elementary school students to understand the physical quantity "density""?

Table 2. Survey instrument for cognitive attribute belief in relation to the self (MP 1, n = 24).

Detected Construct	Number of Items	Cronbach's α
TK	7	0.84
CK	3	0.78
PK	7	0.67
PCK	4	0.71
TCK	3	0.77
TPK	5	0.58
TPaCK (elementary school teaching)	5	0.78
TPaCK (science education for the elementary school)	8	0.82
TPaCK (able to explain technical functions in a way that is suitable for children)	11	0.88

These open-ended questions captured the knowledge of selecting and adequately scheduling digital media for explicit instruction in combination with the knowledge domains of TPaCK.

A separate coding manual was designed for this purpose.

This coding manual was deductively derived from statements on the open-ended questions coded into two or three categories based on the complexity or degree of the answer's interconnectedness (cf. TPaCK model [21]):

- Category 0—no matching answers;
- Category 1—answers can be assigned to one or more of the following knowledge domains: TK, CK, and PK;
- Category 2—answers can be assigned to one or more of the following knowledge areas: PCK, TPK, and TCK;
- Category 3—answers show the highest level of elaboration and show a connection of all knowledge areas (TPaCK).

The individual subcategories/knowledge areas were enriched inductively (data from a pilot sample, n = 28) with examples. The open-ended questions coded in this way were analyzed with a frequency analysis [72], thus enriching the quantitative evaluations with qualitative elements. The assessor agreement showed weak to very good conformity with the Cohens Kappa calculation, suggesting a satisfactory coding manual.

In this paper, we specifically reported only the results of our survey on the cognitive trait, "Belief in Own Ability in the Reference System Self" (TPaCK), and knowledge (expertise in floating and sinking—basic concepts of displacement, buoyancy, and density), as we defined this as the most important quality feature of our intervention (see section on Professional Competencies). The data were analyzed using a mixed-methods approach.

To determine the explanatory differences in the students' beliefs between the first and second times of measurement, the SPSS program (version 28) was used to calculate the statistical mean difference between the two time points of measurement. Subsequently, the statistical significance of these differences was determined using a T-test for dependent samples (one-sided test procedure), and then the effect sizes (Cohen's d) were calculated to derive the practical significance. To describe the differences in knowledge, students' responses to the different MPs were categorized. Thus, the frequencies at which the categories were assigned to the different MPs were contrasted (exploratory).

10. Results

In this chapter, we first descriptively outline the baseline conditions regarding the cognitive trait belief in relation to the respondents' self to MP1 as well as the change to MP2 (Table 3). Subsequently, the scales on the cognitive trait knowledge are described, and, finally, the frequency analysis is presented in order to elaborate on the quantitative results.

Table 3. Comparisons of mean values: Cognitive attribute belief in relation to self (MP1–MP2).

	M MP1	M MP2	Delta	T	df	*t*-Test (1-Seitig)
TK	3.11	3.40	−0.29	−2.85	23	0.004
CK	3.02	3.19	−0.16	−1.59	23	0.061
PK	3.57	3.73	−0.16	−1.67	23	0.053
PCK	2.90	3.34	−0.43	−3.01	23	0.003
TCK	2.94	3.36	−0.41	−3.35	23	0.001
TPK	2.62	3.23	−0.61	−3.87	23	0.0003
TPaCK (elementary school teaching)	2.60	3.03	−0.42	−4.06	23	0.0002
TPaCK (science education in an elementary school)	2.86	3.34	−0.47	−3.36	23	0.0013
TPaCK (able to explain technical functions in a way that is suitable for children)	4.46	4.42	−0.03	0.28	23	0.791

Without a clear approving or disapproving tendency, i.e., in the middle range of the scale, respondents frequently rated their own abilities in the knowledge domains of the TPaCK before the beginning of the intervention (but after two or three subject-specific teaching methodology modules related to the teaching and learning of science as part of subject teaching) (Table 4). At the same time, the data evidently showed that, on average, students rated themselves above the mean of the scale regarding the knowledge areas TK, CK, and PK (see TPaCK model) (the average was slightly above the scale average) than regarding the overlapping areas (PCK, TCK, and TPK) (the average was below the scale average). Similarly, with a slightly more positive tendency was the self-efficacy of the technical knowledge to be able to explain technical functions (e.g., of a touch screen or the Internet) to students (M 4.26, SD 0.84; the achieved mean value was above the scale average). Based on the statistical mean, the self-efficacy of their own ability to consider all areas of knowledge (TPaCK) in relation to (science) teaching in an elementary school was, again, rated slightly lower by the respondents.

Table 4. Cognitive attribute belief in relation to self-MP1, respondent's baseline (n = 24).

Detected Construct	M	SD
TK *	3.11	0.63
CK *	3.02	0.65
PK *	3.57	0.41
PCK *	2.90	0.49
TCK *	2.94	0.69
TPK *	2.62	0.74
TPaCK (elementary school teaching) *	2.60	0.64
TPaCK (science education in the elementary school) *	2.86	0.60
TPaCK (able to explain technical functions in a way that is suitable for children) **	4.46	0.84

* Likert scale with 5 gradations (coding 1 to 5), ** Likert scale with 7 gradations (coding 1 to 7).

Following (going through) the treatment, almost all cognitive characteristics (conviction, related to the self) showed higher values. These differences were statistically significant with two exceptions (CK and PK), and were accompanied by clear effect sizes. The areas of knowledge that were already rated as high in MP1 showed rather weak to no effects (CK, PK, and TPaCK technical functioning) or barely medium effects (TK). However, medium to high effects can be observed for the change in beliefs that were below the average rating at MP1 (PCK, TCK, TPK, and TPaCK (science education in an elementary school)).

The frequency analysis (Table 5) of the open-ended questions on the cognitive trait knowledge (selecting and adequately scheduling digital media for explicit instructional content of swimming and sinking) revealed that significantly more responses were produced in the non-networked knowledge areas (TK, PK, and CK) after the implementation of the treatment (category 1), than in MP 1. Likewise, an increase in responses in the networked areas, PCK, TCK, and TPK (category 2), was recorded, whereas responses in the knowledge area, TPaCK, did not occur more frequently (category 3). Additionally, the rapid decrease in non-matching responses (category 0) is noteworthy.

Table 5. Absolute frequencies of occurrences of the categories in statements of students.

	MP 1	MP 2
Category 0	30	9
Category 1	81	118
Category 2	27	35
Category 3	5	6

11. Discussion and Limitations

Although these results show a positive development over time for the attendance of a university course, and can be described as conforming to theory, e.g., [45], they prove the principal changeability of the cognitive features' beliefs and knowledge with respect to the TPaCK model and the majority of the knowledge domains addressed therein, e.g., [39,47]. We were thus able to prove, once again, that TPaCK can be learned and that we can additionally minimize the special TK and ICT deficits of the prospective teachers described above with an innovative seminar concept. In addition, we were able to foster the integrated areas of TPaCK (TCK, TPK, and PCK), which we observe as a basis for successful teaching-related activities.

However, it must be critically noted that the sample can by no means be considered as representative. On the contrary, it is reasonable to assume that students who participated in the survey were students that were particularly engaged in the study, who invested time in supporting the research, and who generally perceived the seminar in a positive manner. Previously, students chose this seminar from a variety of classes, which is why a double bias must be assumed. Another major point of criticism that needs to be emphasized is that there is currently no comparison with a control group, which would allow us to draw causal conclusions about the relationship between the intervention and the developments shown in the present study. Presently, one can formulate the hypothesis that the conducted treatment, in which the construction of TPaCK and all its components was specifically addressed, might have been the decisive factor for the empirically traced development in the TPaCK-related competency areas. However, this contrast is pending, as is the analysis of the survey data in terms of a longitudinal study at the third measurement point, after the students have planned, conducted, and reflected on lessons on the focused instructional content. A development as a mere test effect is rejected as unlikely. For the purpose of "deliberate practice" [41], a conscious engagement was considered as a necessary prerequisite for competence development. At this point, it cannot be completely excluded that this engagement was encouraged in every student's life, solely after the implementation of a questionnaire.

We observed a second starting point in the fact that the self-efficacy in the knowledge areas, TK, PK, and CK, was above the scale average during the first measurement. This could have ensured that learning opportunities of the treatment could have a particularly good effect on the other components of the TPaCK model (more frequent mention of category 1, frequency analysis). Additionally, it would match the theoretically postulated and empirically proven connections, according to which subject knowledge and pedagogical knowledge are a necessary starting point for the development of pedagogical content knowledge. The data pattern obtained in the present study gives us reason to differentiate between these formulations and to explore the roles of PK and TK in greater detail. The frequency analysis also confirms a better self-efficacy of the respondents in the networked knowledge areas PCK, TCK, and TPK to the MP2, as category 2 was mentioned more often, and, at the same time, significantly fewer answers were presented in category 0.

12. Conclusions: Theoretical and Practical Implications

This study showed that addressing TPaCK in the training of prospective teachers is essential, particularly because prospective teachers begin their studies with comparatively low ICT competencies.

The presented results show that the development of the cognitive trait conviction relating to the self changed as expected, both in relation to the less highly networked knowledge area's technical knowledge (TK) as well as relating to the more highly networked parts of the knowledge areas, such as technological-pedagogical, technological-content knowledge (TPK, TCK), as well as pedagogical content knowledge (PCK) ([21]) over the course of the seminar. We were able to determine a positive development towards stronger expressions, which was predominantly reflected in the qualitative analyses of the free-text answers for the recording of knowledge in the area of TPaCK. On the second date of the survey, however, students still did not succeed in generating answers assigned to the highly interconnected knowledge areas regarding the focused subject content. We assume that the reviewed treatment promotes the knowledge areas of TPaCK, provided that the prospective teachers have previously completed one module each (totaling approximately 15 seminar units), emphasizing (science) subject knowledge and the subject-specific teaching methodology. Thereby, the greatest challenge is that the integration of TPaCK in combination with teaching-related competencies in the seminar means an additional expenditure of time and staff (regardless of amalgamated or integrated address). However, more ECTS credits or personnel will not be made available to the subject-specific training. Nevertheless, we have proven that we are able to foster TPaCK in the available time.

In the second design phase, two treatment variants were compared in order to identify optimal treatment for teacher trainees (experimental and control group design). Therefore, an (1) amalgamated address of the rather networked knowledge domains (TCK, TPK, and PCK) and (2) steadily integrated address within TPaCK interests will be offered and contrasted. Furthermore, based on the videos of the lessons (from the summer term of 2021), non-participative, criterion-guided lesson observations on the lesson quality features [45] are currently in progress, in order to draw conclusions from the actual performance in terms of mastering requirements (cf. models KMK and DCB). On the one hand, we are interested in the quality of the inclusion of digitality in the implemented learning offer of the prospective teachers as an indicator of the acquired competence. On the other hand, in terms of teaching quality research, the extent to which students in the science classroom benefit from such teaching methods regarding their subject-related learning processes, or if they are possibly prevented from doing so, should be examined. This data will be compared to that of design phase two to potentially obtain more precise information on the implementation/realization of teaching, with special consideration of digital media/technologies in primary school science-education classrooms. Within inquiry-based teaching at the university, students will be given the opportunity to participate in these research projects and use the data for their finale theses.

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