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Technology education in primary school using the example of learning robots – development and evaluation of an in-service teacher training concept

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Abstract

The context of the study is the increasing digitalisation of the living environment of primary school students, which is to be introduced into primary schools according to theoretical and educational policy guidelines. In this regard, further teacher training on digital media in classrooms are particularly relevant, on the one hand to promote teachers' digital-related pedagogical knowledge and content knowledge (DPaCK). On the other hand, studies also reveal positive correlations among teacher training, teaching activities, and students' learning outcomes. In-service teacher training courses with adaptive support by a trainer in particular have proven to be effective. Against the background of various research studies on professional development of teachers, a corresponding model of tripartite learning outcomes has been established and serves as a broad theoretical framework. However, the specific relationship between in-service teacher training with adaptive support, DPaCK, and computational thinking of primary school students in the context of the German primary school subject Sachunterricht *has not been sufficiently studied. Therefore, the following research questions can be derived: (1) To what extent does training with adaptive support on the topic of learning robots contribute to the development of teachers' DPaCK? (2) Which effects can be* *ascertained on the students' computational thinking in technology-related* Sachunterricht*? To investigate this relationship, an intervention study in a pre-post design with an experimental group, a control group, and a baseline is appropriate. As results are not yet available at this point, the present paper focuses on the presentation of the theoretical background and empirical approaches.*

Keywords

Technology education; teacher professionalisation; computational thinking; digitalisation; learning robots

Initial situation

Increasing digitalisation has become an integral part of our everyday life and thus affects the entire living environment we find ourselves in (Kultusministerkonferenz (KMK), 2017). Therefore, the living environment of primary school students is also part of this space permeated by digitalisation. This can be seen in the current results of the KIM study (acronym for Childhood, Internet, Media) published in 2021: According to its research results on media equipment in German households in 2020, digital media can be found to a high extent in children's rooms in Germany. As reported by main educators, their children have access to television (100%), internet (99%), mobile phones/smartphones (99%), and computers/laptops (99%) (Medienpädagogischer Forschungsverbund Südwest (mpfs), 2021). The digital medium of a tablet is less widespread (46%) but is already part of almost every second German household (mpfs, 2021). Overall, this study confirms the thesis that digitalisation as well as the use and consumption of digital media are strongly attached to the living-world of primary school pupils (mpfs, 2021). This leads to the central concern of the presented dissertation project, to take a closer look at this initial situation in order to investigate digital media and the associated skills and abilities in the teaching of primary school subjects.

The following sections take a closer look at German educational policy guidelines and theoretical demands regarding technology education. After that a relevant framework for the effectiveness of in-service teacher training is presented that is linked to special teachers' skills and particular students' learning outcomes. Thereupon, research questions can be derived and considerations on the methodological design of the study are presented. Finally, there is an outlook to tasks in the process of research.

Literature review

Foremost, the difference between educational technology and technology education has to be figured out briefly with the intention of a clear understanding of the presented research project. According to Loveland (2012), these two academic subjects are separate but still have commonalities. Nevertheless, distinct characteristics can be found: While educational technology emphasises the use of digital media and information systems (e.g., computer, internet, etc.) to enhance, assist, and support teaching and/or learning processes, technology education aims for technological literacy by which problem solving and critical thinking skills are developed (Loveland, 2012). Against the backdrop of learning robots as specific teaching content, technology education is mainly raised since programming and assessing of learning robots afford competencies of technological literacy such as problem-solving or understanding of its function. Therefore, the focus of this research is put on technology education with learning robots in primary schools. In order to define the term learning robot, it is important to accentuate its difference to usual robot toys, which can be found in many children's rooms (e.g., Fisher-Price, robotic sets by LEGO etc.). Learning robots, however, are characterised by their embedding in teaching settings framed by theoretical and empirical based guidelines. Therefore, robotic toys and learning robots can be the same objects that differ in their use and objective. Specifically, the learning robots BlueBot and OzoBot are being considered here for solving a transport problem or planning traffic routes by programming them accordingly.

Next, it is necessary to give an overview of the current theoretical and educational policy guidelines in Germany concerning technology education at the primary level for the purpose of defining the field of research more closely. Theoretical requirements for technology education in German primary schools (Mammes & Tuncsoy, 2018; Gervé, 2016) are added to general educational policy directives and standards for teacher education as well as for student learning.

German educational policy guidelines and didactic demands

Against the background of digitalisation, there are several theoretical and empirical justified demands for teaching technology-related *Sachunterricht* that call for an intensified addressing and implementing of digital technology/digital media (Schlagenhauf, 2015; Gervé, 2016). By integrating digital media into classrooms, prevention of technological illiteracy is to be achieved so that students are able to participate in social life (Mammes & Tuncsoy, 2018). Furthermore, students should acquire the ability to make judgements and critically self-reflect in the sense of technology education (Schlagenhauf, 2015). In addition, students should learn about functions of technological artefacts in order to develop an understanding for them (Straube et al., 2018; Wiesmüller 2006). This aim is especially important if it is considered that students often have no idea about the function or construction of digital technology (Schumann, 2021), which is why technology education is very important at this point. In this regard, learning with and especially *about* digital media takes a central role (Gervé, 2016; Gervé & Peschel, 2013) so that specifically the relevance of technology education is emphasised again. Further didactic demands relate to the perspective of teachers whose education and advanced training, for example, have to be specified with regard to digital media (Mammes & Zolg, 2015).

Next to these theoretical and empirical justified demands, educational policy guidelines have also been developed to deal with challenges that come with it. One central document is the so-called strategy "*Bildung in der digitalen Welt*" (Education in the digital world) that provides information about the implementation of digital developments in the educational system (KMK, 2017, 2021). This educational policy document does not only address students at all school levels and all school subjects by defining learning goals with regard to digitalisation, but also includes provisions for pre- and in-service teacher education. Based on this, several frameworks for building up students' media competence in school have been developed (Medienberatung NRW, 2020a). Each federal state of Germany has its own framework that partly differs in priority setting, but all have a similar content and target which applies to all school levels and subjects. The framework of North Rhine-Westphalia serves as a specific example in an effort to further define its objectives. The primary objective phrased in this framework is to enable students to use digital media in a safe, creative, and responsible way as well as to provide them with technological literacy that is concerned with informatics (Medienberatung NRW, 2020a). In order to achieve these goals, six areas of competencies have been established which focus on operating and applying digital media, informing and researching by digital tools, analysing and reflecting them, or problem-solving and modelling with and *about* digital media (Medienberatung NRW, 2020a). It appears that these competence areas do not merely refer to educational technology (*operating and applying*, *informing, and researching*), but address technology education as well (*analysing and reflecting*, *problem-solving and modelling*), which can be especially served by the teaching context oflearning robots.

Besides this educational political guideline, which concerns students' education in the context of digital media, there is another document that concentrates on teachers' perspective in North Rhine-Westphalia in order to extend teachers' skills under the conditions of the digital transformation (Medienberatung NRW, 2020b). For this purpose, five already existing fields in which teachers find themselves in (teaching, educating, advising etc.) have been filled with a total of 20 competencies (Medienberatung NRW, 2020b). With the help of these competencies, teachers are requested to design educational processes regardless of school level or subject by utilising opportunities that digital media can offer

(Medienberatung NRW, 2020b). So this framework is not exclusively aimed at pre-service teachers but also finds application in in-service teacher training and the use of digital media in classrooms (e.g., learning robots) comes to the fore.

As it has been already pointed out, the teaching content of learning robots is attributed to technology education which is located in a German primary school-subject called *Sachunterricht*. This term is often translated to *interdisciplinary social and science studies,* but this translation does not suit the multi perspective approach to children's living environment and its phenomena (Thomas, 2015; Schröer & Tenberge, 2023). Due to this fact, the present paper will stick to the German term of *Sachunterricht* that includes a technological perspective and technology education. In the curriculum of *Sachunterricht* in primary schools of North Rhine-Westphalia the engagement with digital media and technology education is particularly assigned to the area "technology, digital technologies and work" in which first experiences with programming as well as reflection on the possibilities and opportunities of digitalisation are specified as teaching content (Ministerium für Schule und Weiterbildung des Landes Nordrhein-Westfalen (MSW NRW), 2021).

Following this synopsis, it can be concluded that a common intersection of theoretical demands and educational policy guidelines for teaching *Sachunterricht* exists. In this setting the question arises as to how these aims, which are demanded by German theoretical demands and educational policy guidelines, can be achieved if teachers are perhaps not sufficiently qualified for this. One possible solution consists of *specific in-service teacher training on digital media*, which helps teachers to build up and develop all relevant competencies for conducting technology education. The effects of such training depend on different aspects and can be noted on various levels which are presented next.

Effectiveness of in-service teacher trainings

To outline the impact structure of in-service teacher-training, an established framework of tripartite outcomes is appropriate. As shown in Figure 1, this simplified model is suited to examine the effectiveness of in-service teacher training and their special features on teachers' professional knowledge, instructional practices, and student learning outcomes (Kleickmann et al., 2015).

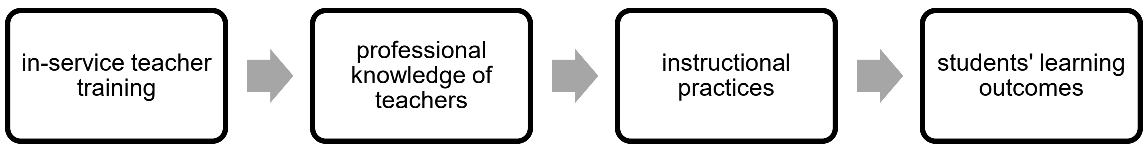

Figure 1. Simplified framework for the effectiveness of in-service teacher training following Kleickmann et al. (2015).

If in-service teacher training is assumed to be the central starting point of the framework, the immediate effect is on teachers who participate in such training. This effect can be determined on different levels in the sense of a model derived from Baumert's and Kunter's (2011, 2013) COACTIV study, which aimed to identify "the qualities that teachers need in order to meet the demands of their profession, with the main focus of interest being on classroom instruction" (Baumert & Kunter, 2013, p. 26). These levels compose professional competence of teachers; they include motivational orientations, beliefs, values, and goals as well as self-regulation (Baumert & Kunter, 2011, 2013). In addition, the professional competence of teachers also comprises *professional knowledge*, whose impact through in-service teacher training is the focus of attention in the present paper (Baumert & Kunter, 2011, 2013). Moreover, professional knowledge of teachers can be differentiated into the various partial competencies, e.g., *pedagogical knowledge*, *content knowledge* and *pedagogical content knowledge* (Baumert & Kunter, 2011, 2013; Lipowsky, 2006). This classification of professional knowledge of teachers has general validity and can therefore be transferred to different teaching settings. In order to be more precise regarding the teaching topic of learning robots, the DPaCK model (*digital-related* *pedagogical knowledge and content knowledge)* can be used, as it describes all those teacher-side competencies that are required for teaching about learning robots. This model is an extension of the TPaCK model (technological pedagogical content knowledge) which includes aspects of digitality (Huwer et al., 2019). Central to the DPaCK model are three knowledge areas which can be divided into *digital-related knowledge (DK)*, *content knowledge (CK)* and *pedagogical knowledge (PK)* (Huwer et al., 2019). Compared with the partial competencies of professional knowledge, correspondences as well as specifications of knowledge areas can be found. Furthermore, there are also intersections of DK, CK, and PK; one of them contains all these three knowledge areas and is called *digital-related pedagogical knowledge and content knowledge (DPaCK)* (Huwer et al., 2019). In this intersection, all considerations from the associated knowledge areas are included. Against the context of teaching about learning robots, DPaCK can be specified by the question as to how primary school students can (further) develop specific digital-related competencies in dealing with learning robots in the subject of *Sachunterricht*. Empirical evidence can be mainly found for the more general impact of in-service teacher training on the professional knowledge of teachers (Lipowsky, 2019; Souvignier & Behrmann, 2017). Other research has shown positive effects of content knowledge, and subject-didactic and pedagogical knowledge on student performance in mathematics education (Campbell et al., 2004; Hill et al., 2005; Rosenshine & Stevens, 1986; Wayne & Youngs 2003). These dependent variables are part of the already presented simplified framework by Kleickmann et al. (2015) and particularly student learning outcomes are now considered in more detail. Due to a lack of research results concerning the DPaCK model, there cannot be specific results about in-service teacher training and their effects on DPaCK or students' learning outcomes. Instead, study results based on TPaCK can be reviewed. Following Guzey and Roehrig (2009), teachers' TPaCK has positive consequences on science teaching and students' knowledge construction as well as problem-solving skills (Guzey & Roehrig, 2009). Taking the teaching setting of learning robots into account, problem-solving skills as a student outcome are particularly essential, which are defined next.

In a framework by Kleickmann et al. (2015), student learning outcomes are perceived in a multi-criteria way as it is demanded by national primary standards for *Sachunterricht* (Gesellschaft für Didaktik des Sachunterrichts (GDSU), 2013). According to the framework, various aspects, such as interest, motivation, or self-efficacy as well as cognitive abilities, are considered (GDSU, 2013). With reference to the learning content of learning robots, the multi-criteria learning outcomes in particular include technological problem-solving ability of primary school students, which can be specified by the models "*Technikkreis*" by Ahlgrimm et al. (2018) or "*Entwicklerkreis zur technischen Problemlösung*" according to Mammes and Zolg (2015). Both models visualise a way to solve an existing problem with the help of technological inventions by passing through various methodical steps or phases (Ahlgrimm et al., 2018; Mammes & Zolg, 2015). Besides, technological problem-solving skills can also be concretised with the help of computational thinking which takes a central role in the presented research project. Wing (2017) has defined computational thinking as "thought processes involved in formulating a problem and expressing its solution(s) in such a way that a computer – human or machine – can effectively carry out" (Wing, 2017, p. 8). Therefore, computational thinking is closely linked to algorithms, modelling, and formalisation and is directed towards solving (technological) problems (Wing, 2017). Digital artefacts are considered in this process but do not necessarily have to be used (Wing, 2017). Wing's description of computational thinking is included in a model published by Barendsen and Bruggink (2019) which complements this definition to a circular scheme (see Figure 2). Additionally, the model differs between the context of our living environment and the content of computational thinking (Barendsen & Bruggink, 2019). The connection between these two contexts is highlighted by the partial working steps *decontextualizing* and *(re)contextuali*sing between living environment and CT-content, *computationalising* and *reflecting* on the found solutions.

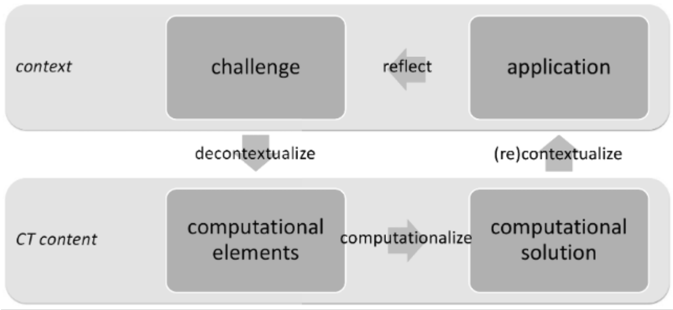

Figure 2. Model of computational thinking according to Barendsen and Bruggink (2019).

A closer look at this model of computational thinking clearly shows parallels to the other models of technological problem-solving mentioned before (Ahlgrimm et al., 2018; Mammes & Zolg, 2015). All these models of problem-solving skills have in common that a certain technological problem has to be composed into manageable (partial) tasks and subsequent reflection and evaluation needs to be done. With regard to learning robots as teaching content and development of computational thinking, the entire framework by Kleickmann et al. (2015) has already been empirically proven to some extent: In the project "*Denken lernen – Probleme lösen (DLPL) Primarstufe*" (Learning to Think - Solving Problems at Primary Level) of the Austrian Federal Ministry of Education, Science and Research (BMBWF) (2018), a professionalisation measure for teachers was implemented, which in a first step increased the methodological-didactic competencies of the teachers. At another level, positive effects on the problem-solving skills of primary school students were also seen (BMBWF, 2018).

Concerning the whole framework, Darling-Hammond et al. (2005) have emphasised that teachers who have qualified through appropriate in-service teacher training have a positive impact on student achievement. However, it should not be neglected that practical scientific research results take an important role in the design of effective and sustainable in-service teacher training, so that the focus must be on features that exactly promote these positive effects. In this context Lipowsky and Rzejak (2019) have summarised important features of effective in-service teacher training, e. g., interweaving input, testing, feedback, and reflection phases. It shows that effective in-service teacher training is linked to certain structural or core features (Lipowsky, 2009; Desimone, 2009). Besides these features, adaptive support of training participants by a trainer was particularly relevant. Van de Pol et al. (2010) consider this support as an interactive scaffolding-process, in this case, between trainer and training participants. The main characteristic is the tailored support of the learners that decreases over time while responsibility for carrying out a task is progressively transferred to the learner (van de Pol et al., 2010). However, few study results can be found that explicitly focus on the role of scaffolding in in-service teacher training. Based on this, a possible perspective is provided by Kleickmann et al. (2015), who have examined the effectiveness of in-service teacher training with adaptive support by the training leader. In this case, expert scaffolding measures in in-service teacher training courses represent the relevant feature of the training, whose advantages clearly emerged in the study. Both an improvement in quality of teaching (challenging student conceptions, d = 1.05) and an increase of the students' understanding of science (d = 0.55) were shown (Kleickmann et al., 2015).

Research objectives and questions

Despite the contemporary research, the specific relationship between in-service teacher training with adaptive support, DPaCK, and computational thinking of primary school students remains unclear. As it can be inferred from the previous overview, one reason is insufficiently recorded variables of the framework (content knowledge and pedagogical knowledge) which are central to the presented research project. Another reason can be found in a lack of research in the context of computational thinking in technology-related *Sachunterricht* at primary schools. Next to an investigation of this specific relationship, the research project aims to develop an evidence-based in-service teacher training for the use of learning robots in primary schools. From this, the following research questions can be derived: (1) To what extent does in-service teacher training with adaptive support on the topic of learning robots contribute to the development of teachers' DPaCK? (2) What is the impact of this in-service teacher training on the students' computational thinking in technology-related *Sachunterricht*?

Methodology

To answer these research questions, an intervention study in a pre-post-design has been designed. The sample will consist of teachers who attend a special in-service training session in the context of learning robots and their primary-school students. The study participants will be divided into three groups: *experimental group*, *control group* and *baseline* that differ in their approaches (see Table 1).

Table 1. ***Possible Study Design***

	teachers: Pre-survey	teachers: Intervention	teachers: Post-survey	students: Pre-survey	students: Teaching	students: Post-survey
Experimental group	Questionnaires for the inquiry of DPaCK	In-service teacher training in the subject of '*learning robots*'	Questionnaires and interviews for the inquiry of DPaCK	Questionnaires for the inquiry of Computational Thinking	'*Sachunterricht*' in the subject of '*learning robots*' supported by teaching material (EG + CG)	Questionnaires and interviews for the inquiry of Computational Thinking
Control group		*No intervention*	*No post-inquiry*			
Baseline		*No intervention*	Questionnaires and interviews for the inquiry of DPaCK		*No teaching (BL)*	

The possible intervention contains a specific in-service teacher training on the topic of learning robots, whereby the training can be adapted from an existing in-service teacher training concept from *teachwood digital* (*project on technical, crafting and digital work at primary schools*) (Tenberge et al., in print) so that an included single session can be further developed for the content context of learning robots. The teachers in the experimental group receive this training as an intervention and are required to conduct appropriate lessons with their school classes after their training. For teaching purposes, the teachers have access to already designed teaching suggestions, which are included in the teaching material presented in the in-service teacher training. Accordingly, in the experimental group, both teachers and students undergo pre- and post-surveys in order to collect data about teacher-side DPaCK and students' computational thinking skills. In contrast, the teachers in the control group do not receive any intervention but are just provided with teaching material with the intention of conducting corresponding lessons with their classes. This material is thematically identical to the one distributed to the experimental group, and the students of the control group also participate in pre- and post-surveys. A baseline is intended as a third group aiming to be able to exclude temporal effects in the sense of test repetition. For this reason, pre- and post-surveys are planned for teachers and students in the baseline group without any intervention, material distribution, or teaching having taken place. For the purpose of ensuring the variation of the independent variables of the in-service teacher training, a treatment check of this training will be conducted. The training courses will be videotaped and checked by two independent raters.

For the data collection, questionnaires in the form of paper-pencil-tests are suitable for the survey of teachers and primary school students whereby these are supplemented by occasional guided interviews. In order to gather data about teachers DPaCK, a paper-pencil-test based on proven TPaCK questionnaires (e.g., Schmidt et al., 2009; Bilici et al., 2013; Schmid et al., 2020) will be adapted. In addition, teachers will also be asked about their computational thinking, as it is an integral part of their specific DPaCK as well. A suitable questionnaire for surveys on computational thinking of teachers and primary school students is the test by Brämer et al. (2022) which has been used before to examine computational thinking of students at university and primary school (see also Román-González et al. 2017). Next to this, students' problem-solving-ability can be investigated by Bohrmann's test (2017) that has to be adapted for the specific context of learning robots. This test also includes items for the investigation of primary school students' interest. For the inquiry of students' motivational forms of regulation, a self-regulation questionnaire (SRQ) in allusion to Ryan and Connell (1989) is useful (see also Tenberge, 2002). All these questionnaires do not only contain closed questions, but also allow open responses. Furthermore, primary school students' concepts about (learning) robots will be explored in a piloting session. First considerations about data evaluation figure out a qualitative questionnaire analysis which is complemented by a qualitative content analysis of the individual interviews (Kuckartz, 2018).

Outlook

Due to the current status of the research project, no further methodological details or preliminary results can be presented at this point. Instead, an outlook on oncoming tasks is given. As a next step the relation of teachers' beliefs and their DPaCK will be theoretically founded for the purpose of integrating this relation into the research project. After having elaborated the theoretical background with a focus on conditions for success and effectiveness of teacher training, an in-service teacher training about learning robots will be further developed based on the concept of "*teachwood digital*". Thereby theoretical background considerations as well as empirical findings will be taken into account. Subsequently, survey instruments will be adapted and interview guidelines for teachers and students will be created. Eventually, the DPaCK-questionnaire will be piloted in the context of "*teachwood digital*". This piloting is particularly relevant for the development of a corresponding research instrument based on TPaCK questionnaires, so that the main study is planned for 2023.

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