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Learning to teach and teaching to learn about Robotics at primary level: Professionalization for inclusive technology education integrating Theory and Practice

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Abstract
The professional development of teachers is considered a central task of teacher training and therefore also for teaching technology education in an era of digitalization. The anchoring of technology and digital technologies is becoming a mandatory task in teaching especially due to curriculum requirements and an increasing importance of learning with and learning about digital technologies for dealing with everyday problems (Ministry for Schools and Education of the State of North Rhine-Westphalia (MSB NRW), 2021). The lack of emphasis on technology education in teacher training for primary school teachers in Germany presents a significant obstacle to the integration of technology education into the curriculum. Moreover, the individual decision on the extent to which technology education is addressed in the multi-perspective school subject 'Sachunterricht' leads to insufficient consideration. Furthermore, studies have demonstrated that the self-efficacy and subjectively assessed competencies of teachers have an impact on the inclusion of technology in 'Sachunterricht' (Möller, Tenberge & Ziemann, 1996). It is unclear how (prospective) teachers can acquire and test the necessary competencies to be able to carry out digital-technology and inclusive lessons in an educationally effective manner. To address this question, the present article employs a design-based research approach (Euler, 2014) to test and evaluate theoretical constructs in practice by prospective teachers.

Keywords
Inclusive Education, learning-robots, pre-service teacher education, problem-solving and computational thinking

Introduction
In the context of global challenges such as climate change and energy transition, digital and technical solutions are becoming increasingly important. As Müller and Schumann (2021) demonstrate, the topic of digital technology education in primary schools is gaining prominence, particularly in the field of education (Müller & Schumann, 2021). The acquisition of competencies enabling participation in a digitally mediated world, including an understanding of digital and algorithmic principles, is a key factor in promoting general maturity and social integration (Bohrmann, Weber & Tenberge, 2019). It can be reasonably assumed that the professionalization of educators, particularly in the context of technology-related instruction, will play a pivotal role. The rationale for integrating digital technology into

the educational curriculum can be attributed to its cultural and scientific value, as well as its societal importance in the context of technological advancement and its impact on lived reality (Theuerkauf, 2009).

The significance of inclusive pedagogical practices for diverse student populations is another central focus. Although Inclusion and inclusive education are quite well conceptualized from a theoretical perspective there is a lack of transfer to teachers' professional ways of teaching in inclusive learning environments. This necessitates the integration of theoretical and practical elements in teacher training, encompassing both the academic curriculum and professional development.

The skills needed to participate in the digitalized world are summarized in the 'future skills' model. These include reflective thinking and communication skills (Bates, 2024). In the context of technology education, the two aspects of 'thinking skills' and 'digital skills' are particularly significant. Bates (2024) highlights cognitive skills, which are fundamental to analysing complex problems and developing innovative solutions. The importance of digital skills and the resulting subject-specific use of digital technologies in educational institutions is also emphasized (Bates, 2024).

As a result, it is important to integrate these skills into teacher education. The aim of this research article is to investigate how the integration of theory and practice affects the professional development of pre-service teachers.

The present article falls into five further sections, of which the first will outline the basic concepts addressed. After justifying the requirements of inclusive technology education and problem-solving, section three analyses the teaching setting regarding the role of teachers in an inclusive learning environment, the children's perspective with the needs of children and thinking ahead by integrating modes of representation across a spiral curricular structure. Based on the analysis, this is then placed in the context of teacher professionalisation.

Literature review

Unlike in many other countries technology education at primary level in Germany is integrated in one school subject along with scientific and social scientific education called 'Sachunterricht' (Schröer & Tenberge, 2023). The subject encompasses scientific, social, geographical, historical and technological perspectives on children's living environments in a multi-perspective way. The maxim of teaching 'Sachunterricht' at primary level in an inclusive way provides an essential framework for this fundamental part of education in the German educational system (Schröer & Tenberge, 2023). The multi-perspective character of the subject serves as a potential for inclusive education. Its purpose is to enable all students to explore their environment and examine objects from different perspectives (Academic society for Sachunterricht (GDSU), 2013) ['Sachunterricht' translated from German: social studies]. The objective is to integrate students' prior experiences and their personal contexts, and thereby promoting comprehensive understanding. Therefore, 'Sachunterricht' is designed to provide all students with equal access to education and opportunities for participation in the learning process (Blömer-Hausmanns & Schnell, 2022). Furthermore, 'Sachunterricht' should be implemented in a systematic and structural manner, considering the social and individual differences between students, to ensure that all students have equal access to high-quality education.

Integrating Technology education at primary level aims towards ensuring that students learn elementary forms of technological behaviour and acquire technological knowledge and skills that are relevant to everyday life (Möller, 2002). It is evident that technology is present in children's living environment, as they invent and operate technology and use it to discover and solve problems (Ahlgrimm *et al.*, 2018). Technology education at elementary and primary level is both fact- and child-orientated (Schröer & Tenberge, 2023). Fundamental to teaching and learning technology at an early stage is therefore, to promote interest, enable reflective application and promote the cognitive development of students (Mammes & Zolg, 2015). Therefore, it is necessary to develop differentiated technological ways of thinking, working and acting using exemplary and interest-led objects (Möller & Wyssen, 2018) and to apply methodological and content skills acquired at school in differentiated everyday situations (Landwehr, 2017). Another element is the promotion of a critical perspective towards technology (GDSU, 2013), as students lack an understanding of underlying functional principles in technological artifacts, problems and processes (Mammes, 2001). Finally, Technology education should contribute to the development of awareness of how to utilize technology in an environmentally and socially responsible manner (Steinmann, 2019).

In view of an increasingly complex digital-technological world, the promotion of digital skills in a problem-oriented way, such as the qualified and reflected application, use and active participation in shaping digital media, is essential (Scheibe *et al.*, 2021; Schmeinck, 2022). Problem-orientation serves as a concept for 'Sachunterricht' teaching (Beinbrech, 2015). It is characterized by teaching-learning processes, that consider the individual learning requirements of students, can contribute to the development of students' self-efficacy expectations (Steinmann, 2019). The starting point for problem-oriented technological 'Sachunterricht' lessons are problems related to the living environment (Finkbeiner & Eibl, 2023). Problem-solving as it's central methodical approach is also present in all models of Computational thinking (CT) (Kärcher *et al.*, 2024). According to Wing (2006) „computational thinking involves solving problems, designing systems, and understanding human behaviour, by drawing on the concepts fundamental to computer science. Computational thinking includes a range of mental tools […]"(Wing, 2006, p. 33). Hence, computational thinking in digital and analogue environments is regarded as a qualification for social participation and is becoming increasingly important in schools (Wing, 2006; Senkbeil *et al.*, 2019). The competencies of Computational thinking are interdisciplinary and fundamental to various domains of knowledge that enable (computer-aided) problem-solving (Senkbeil et al., 2019). Computational thinking encompasses a wide range of competencies, which are described in the competence model of the International Computer and Information Literacy Study (ICILS) (Fig. 1).

The model demonstrates that the integration of content-related competencies, problem-solving abilities, and digital literacy skills can be promoted through CT approaches. CT can contribute to the development of 'future skills' in students. The acquired CT competencies facilitate students' future professional and social lives by fostering the development of problem-solving abilities with digital relevance (Kärcher et al., 2024).

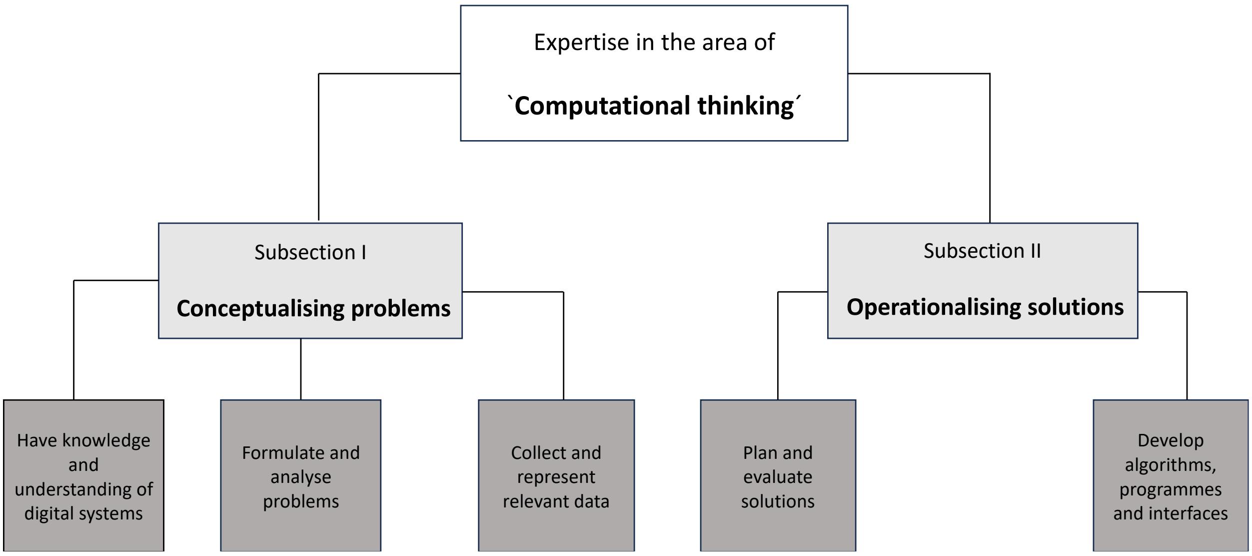

Figure 1: CT- competence model (Senkbeil et al., 2019, S. 101). Translated by Schröer et al., 2024.

The two domains the competence model comprises – conceptualization of problems and operationalization of solutions – extend beyond the mere utilization of hardware and software. They are concerned with the resolution of problems which frequently occur through the development and application of algorithms, which are then made accessible to digital systems, such as computers.

The initial stage of this process is the conceptualization of problems. This necessitates an understanding and processing of the problem in question, as well as the development of potential solutions. A fundamental prerequisite for this is a comprehensive grasp of digital systems and their interactions. It is essential that students learn to identify the characteristics of digital systems and their interconnections. This should facilitate an enhanced comprehension of both digital and analogue realms, and subsequently inform the resolution of problems. This understanding enables students to conceptualize problems and to describe the tools and systems they employ. In the formulation and analysis of problems lies another aspect of the competence model that is geared towards enabling students to divide problems into smaller components, and to integrate encountered solutions with new ones (Senkbeil et al., 2019). Another aspect of this competency is the representation and collection of relevant data. As a result, students can assess the efficacy of proposed solutions.

The second area of focus – ‘Operationalizing solutions’ – encompasses the creation, implementation, and evaluation of algorithmic problem solutions. This includes planning, implementation, testing, and assessment of solutions regarding their transferability to everyday problem-solving scenarios (Senkbeil et al., 2019). This encompasses the capacity to define requirements in relation to intended solutions, as well as the ability to assess algorithms and solutions from multiple perspectives using criteria-based evaluation. The second aspect, "Development of Algorithms, Programs, and Interfaces" primarily concerns the conceptual development of algorithms and programs, as well as their automatization and execution. The development of Computational thinking can be facilitated in primary education using programmable digital technological artifacts such as microcontrollers like the Calliope mini™

and learning robots (e.g. BlueBot™). Learning robots, unlike typical robot toys, are characterized by their integration into educational environments guided by theoretical and empirical frameworks (Janicki & Tenberge, 2023).

The BlueBot™ is a robot designed for use in grades one to six (Bohrmann et al., 2019). The upper surface of the robot contains the controls, which enable forward and reverse motion, as well as left and right turns. Additionally, there is a pause, a reset, and a start button. BlueBots™ can be employed in authentic learning environments. They enable students to adopt positions that facilitate optimal imitation of the BlueBot™ movements (Miková *et al.*, 2022) and offer educators the flexibility to differentiate their instruction in a multitude of ways. Routes can be adapted to suit the needs of the learners, and the number of steps in the process can be increased or decreased as required. Furthermore, the incorporation of a notation of the sequence of instructions can be implemented in various ways (Bohrmann et al., 2019).

The microcontroller board Calliope mini™ represents a significant advancement in the field of informatics teaching and learning, particularly for students in their third year of schooling. Its objective is to illustrate and promote the accessibility of programming. By providing a straightforward and multifaced programming environment, it facilitates a gradual introduction digital technology. The Calliope mini™ is distinguished by the integration of a multitude of components, already present on the circuit board. These include LED displays and microphones, enabling students to undertake a diverse range of experiments and projects without the need for additional hardware. The programming is carried out via a software application executed on a laptop or tablet computer. The Calliope mini-board contributes to the deepening of understanding of digital technologies and the stimulation of interest in informatics among students of all age groups (Bergner & Leonhardt, 2019).

Programmable technological artifacts in general are considered to offer the potential to integrate digital media into inclusive teaching and learning (Wassermann, 2021). They have the capacity to enthuse students about informational learning (Tengler, 2020). The utilization of learning robots and microcontrollers in inclusive science education enables a transformed interaction with educational content, as robots possess a particularly motivating effect (Wassermann, 2021). The collaboration with learning robots is particularly fruitful in integrating productive action with Computational thinking. The objective is to guide students towards abstraction of problems through interaction with learning robots (Bohrmann et al., 2019).

The integration of learning robots into 'Sachunterricht' becomes increasingly important in recent years (Tengler, 2020). As innovative educational tools, they offer the potential to promote algorithmic thinking and influence motivation and interest (Wassermann, 2021).

The perception of autonomy and competence are key aspects of motivation. Haase (2017) posits that the consideration of these aspects can have a profound motivational impact. Making independent decisions and experiencing success enhances the engagement and interest of learners. A study by Bieg and Mittag (2009) indicates that there are both subject-specific and gender-related differences in interest in learning robots. In addition to the academic influences, familial support is also a significant factor (Bieg & Mittag, 2009). Lichtblau (2014) emphasizes that a supportive home environment can enhance students' interest, motivation and engagement in the academic context (Lichtblau, 2014). Another factor influencing motivation is the relationship between teachers and students. Bieg, Backes and Mittag (2011) demonstrated that a supportive and encouraging teacher-student relationship enhances intrinsic motivation among students. An open and respectful teacher-student relationship fosters a positive learning environment that can enhance students' interest in 'Sachunterricht' (Bieg, Backes & Mittag, 2011).

It can be concluded that prospective teachers of inclusive, problem oriented 'Sachunterricht' are given a wide range of responsibilities. The extent to which prospective teachers are prepared for these tasks is discussed below.

Problem statement – Aspects that define a professional teacher

In the preceding explanation, characteristics of inclusive digital-technology education 'Sachunterricht' have been delineated. The heterogeneity of learners is becoming increasingly pivotal in the design of teaching and learning (Dexel & Kratz, 2022). Digital-technology education must be firmly established within the curriculum of primary schools to meet the changing demands of society and to promote the ability to apply knowledge, motivation and interest in the field of informational technology. This should be achieved by encouraging students to learn *with*, *about* and *despite* digital media (Döbeli Honegger, 2017; Tengler, 2020). It is therefore essential to develop Computational thinking abilities, as they are applicable across different subject areas and encompass both computer-assisted and independent analogue problem-solving skills (Senkbeil et al., 2019). The most positive motivational experience associated with the educational use of learning robots is essential for students to experience autonomy and competence and for them to develop a long-term interest in digital technology (Wassermann, 2021; Haase, 2017).

Considering the ongoing debate surrounding the professionalization of teachers in a digital era, we assume a fundamental role for the design of technology education especially at primary level. The professional conduct of teachers in technological 'Sachunterricht', both within the context of the school curriculum and particularly in the context of teacher training, is characterized by a high degree of complexity. It is not only necessary for teachers to gain subject-specific knowledge from different academic disciplines to deliver effective lessons, but they must also engage in a nuanced examination of the characteristics of the subject area of technology.

These challenges underscore the importance of a theory-practice integration that is both quantifiable and qualitative, and that assesses the impact of such integration on the professionalization and self-efficacy of prospective teachers. These considerations inform future teacher education, at all stages. The issues are addressed in this article in the context of three key themes: (1) *teachers' role in an inclusive learning environment*, (2) *integrating modes of representation across a spiral curricular structure*, and (3) *an empirically represented children's perspective to the consideration of their needs*. These themes are discussed and then brought together for a final analysis in the conclusive chapter.

Integrating theory and practice

The following section integrates considerations with the practical experiences that three pre-service teachers gained during their apprenticeship. During a micro-teaching experience that is considered to have positive effects on students' knowledge and self-efficacy in an academic context (Schröer & Tenberge, 2022), technology related 'Sachunterricht' was planned in a seminar and carried out in accordance with the criteria set out for the micro-teaching context. The experiences were evaluated and systematized based on the aforementioned theoretical considerations. According to the methodical frame of design-based-research, the systematized evaluations were used as a *beta-testing cluster* (McKenney & Reeves, 2019) for further development of the intervention.

Three spiral curriculum units on learning robots were taught. To facilitate a more detailed planning of the teaching units, the students' prior experiences were evaluated in advance using self-developed assessment tools developed by the research group for teaching and learning Social and Scientific Studies with Special Needs Education at Paderborn University. These findings were then used to inform the design of the teaching units.

The intervention was conducted during the school entry phase. The BlueBot™ was selected as a shared instructional object. The objective of the intervention was to develop competencies in *chain-based* programming using path problems. A subsequent instructional unit was conducted in a third-grade classroom. The BlueBot™ was employed as a shared learning subject into enhance students' problem-solving abilities (Schröer & Tenberge, 2023). Building upon this unit, a subsequent unit was conducted with the microcontroller Calliope mini™. The acquired technological abilities were revisited and expanded upon in the context of block-based programming.

The following section will examine the role of teachers in said inclusive learning environment and the children´s perspective or how to consider needs in a digital-technology learning environment. Both will be revisited in the third perspective: Thinking ahead - integrating modes of representation across a spiral curricular structure. This will be done with a view to analysing the professionalisation of prospective teachers for technology-related ‘Sachunterricht’.

Teachers’ Role in an inclusive learning environment

It has become evident that there are significant shortcomings in the quality of teaching and learning in Germany, particularly in primary schools, following the global pandemic. The pandemic has demonstrated that many primary school teachers lack the necessary skills to effectively integrate digital media and promote independent learning (Maennig-Fortmann & Hamm-Pütt, 2021). In the field of education, there is a constant demand for the teaching curriculum to be updated and modernized, particularly in terms of digitalization. This requires teachers to possess a range of skills, including technological, pedagogical and digital competencies (Haase, 2017). However, these skills are often not adequately addressed during the training of prospective teachers at German universities, with further training opportunities being insufficiently available (Drossel *et al.*, 2019). This leads to the question of how prospective teachers can be trained to meet the aforementioned expectations.

In the context of Paderborn University’s teacher training program, students can further their education and theoretical knowledge in the field of digital and technology education, with a particular focus on the practical application of their learning.

The instruction conducted within this framework was planned with a focus on learning through shared objects, as advocated by Feuser (2011). According to Schröer and Tenberge (2022), a shared learning object is essential for inclusive science education. Through this shared learning object, equal and equitable participation of learners is facilitated (Schröer & Tenberge, 2022), allowing all students to engage in inclusive instruction. In the context of the aforementioned instruction, students collectively interacted with the BlueBot™ and the Calliope mini™.

To fulfil the requirements of inclusive teaching, the students' previous experiences were assessed at the beginning of each teaching unit. This approach is consistent with the assumption that building on students' experiences and knowledge are fundamental to the design of ‘Sachunterricht’ lessons (Schönknecht & Maier, 2012). According to Buholzer’s (2006) model of diagnosis and support, building on previous experiences is included in the diagnostic skill set. This phase among the diagnosis and support cycle serves to collate information on the students' previous experience in key learning areas, thus enabling the identification of their level of performance regarding learning prerequisites, learning processes and learning statuses. This information is used to adapt teaching in the most effective way (Buholzer, 2006). The survey of prior experience was carried out with the help of a test around computational thinking. Upon analysis of the results, it was determined that the students had already acquired prior experience with the fundamental principle of input, processing and output. Consequently, the lessons were tailored to align with the students' competencies. In addition to recording previous experience, the lessons were adapted to align with the students' learning level. The introductory task, "*human robots*", which was previously conducted in an intervention, was adapted regarding *block-based* programming.

After the students had completed the adapted introductory task, the other tasks were carried out using a station learning design. The tasks and problems could be completed independently of each other. The order of the tasks could be chosen by the learners in partner or group work, so that individual learning paths were chosen based on interests and abilities and the children's learning behaviour could be coordinated easier (Reich, 2014). The station learning method was also used in the unit with the Calliope mini™. The individual tasks were separated by colour and space and labelled accordingly to enable students to make an informed choice.

In the interest of inclusive teaching, individual support measures such as hint cards were made available. Different types of tasks with different levels of difficulty allowed for differentiation in the teaching of technological ‘Sachunterricht’. Pupils were able to choose between individual tasks for programming with the Calliope mini™. The individual tasks differed in terms of performance level, implementation, presentation, instructions and finding and correcting errors in a programmed presentation. Differentiating the tasks allows for inclusive teaching that is designed for all children. These lessons are based on each child's learning needs, so that each child's skills can be developed (Kaiser & Seitz, 2020).

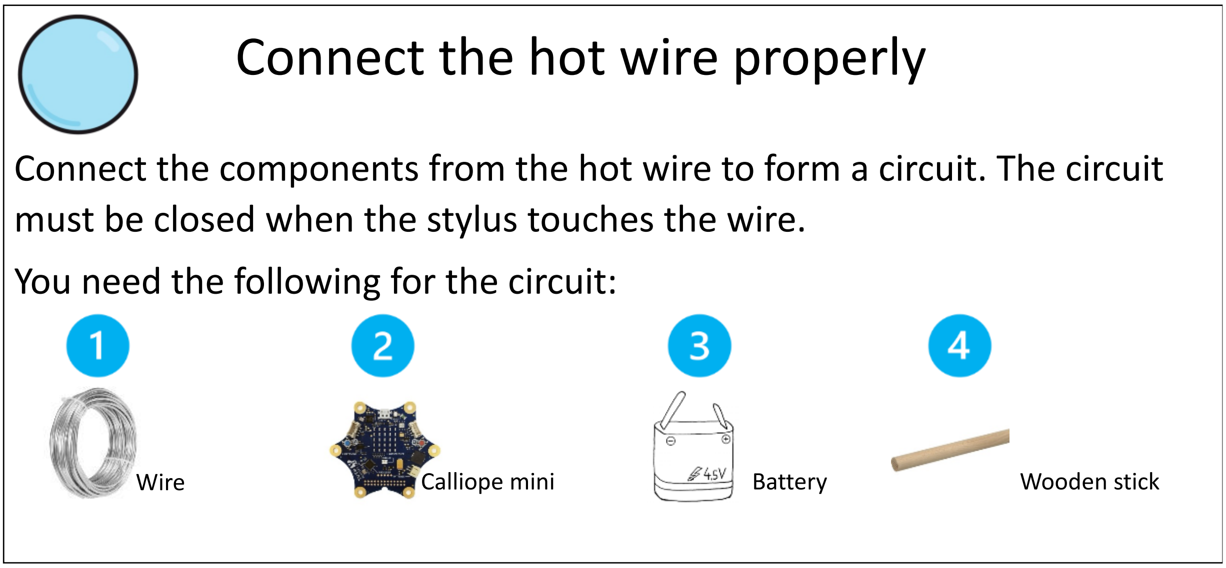

Figure 2: Hint Card Calliope mini (Schröer & Tenberge)

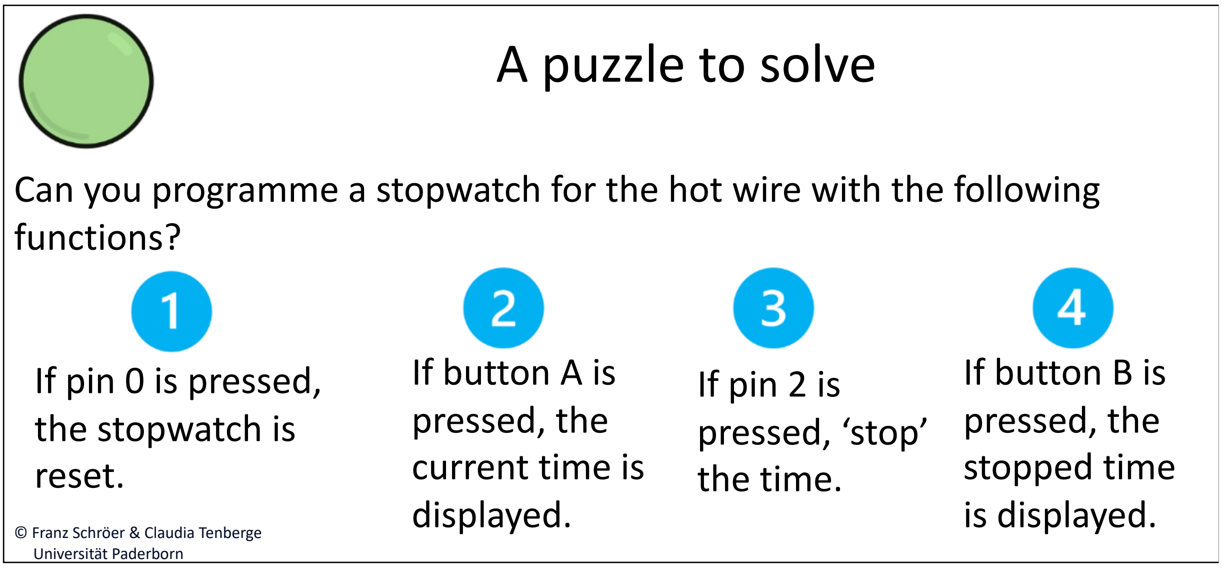

Figure 3: An open problem-based task (Schröer & Tenberge)

The hint cards could be used to solve any problems that arose, allowing for individualized further work. The choice of whether to use one or more of them was left to the students but scaffolded by the teacher. This allowed teachers to support students individually so that a higher level of performance could be achieved without anticipating the solution (Kaiser & Seitz, 2020).

Scaffolding measures were also in place in the classroom settings. According to the scaffolding framework of Van de Pol et al. (2010) the areas of fading and transfer of responsibility to the learners were emphasized. Fading refers to the needs-based reduction of support by the teacher which occurs in interaction with the learner's level of development and diagnostic behaviour, as well as the transfer of responsibility. Complementary to fading, the transfer of responsibility involves handing over responsibility by having learners perform tasks increasingly independently (Van De Pol, Volman & Beishuizen, 2010). The teacher transferred responsibility to the learners by, for example, allowing them to choose the task formats. Learners received support during this phase of the work if they needed it. When the teacher identified need for support in the situation and was able to provide individual support to the students.

The station learning tasks were carried out by the students in partner and group work. This included working in pairs on programming with the Calliope mini™ and in groups of four with the BlueBot™. This ensured collaborative learning and peer-communication, which goes beyond working in groups and puts particular attention to individual responsibility, mutual support, appropriate use of social skills and reflection on group processes (Scheidt, 2017). Of relevance here is a positive interdependence, which assumes that collaboration only works when there is a common goal.

Because of the common goal and the variety of implementation and operation, the aspects of cooperative learning are fulfilled. The common goal was always given, so the task formats required students to work together, try things out and discuss their solutions. Furthermore, the teacher ensured that the students took turns in programming by entering the code sequence in BlueBot™ or by inserting the codes in the correct order in the programming environment.

Children’s perspective: How to consider children’s needs in a digital-technology learning environment

Methodological and teaching and learning possibilities for taking learning needs into account are to be outlined in the context of testing needs-oriented inclusive ‘Sachunterricht’. The results of a questionnaire survey, that is supposed to measure the satisfaction of basic psychological needs (autonomy, competence and social relatedness) (Ryan & Deci, 2000) in different situations or in interpersonal interaction (Schröer & Tenberge, 2021) serve as a basis for the conception of this lesson.

The unit first introduced the new topic of 'robots' with two video impulses. Subsequently the fundamental principle of input, processing and output was developed and the BlueBot™ as a device was introduced. Afterwards, the students worked in groups for three lessons on various problem-based tasks. The design of the lessons considered different aspects that aim at satisfying basic psychological needs. On the one hand, students should learn together in cooperative and pedagogical playful forms and achieve competence to satisfy their need for social relatedness. In addition, differentiation measures and self-control aimed to satisfy their need for competence (Ryan & Deci, 2000; Haase, 2017). This need was also addressed through constructive feedback and a transparent presentation of learning progress and task limitations (Haase, 2017). The open and practical concept of explorative and problem-oriented teaching, taking into account the relevance to everyday life, was designed to meet the need for autonomy (Tenberge, 2002). In addition, station work, and the associated freedom of choice and self-control supported the need for autonomy. Furthermore, autonomy is supported by the possibility to design one's own tasks and promoted self-regulation of the learning process, thus preventing over- or underchallenge (Wood, Bruner & Ross, 1976).

The lessons were evaluated in subsequent interviews, followed by a qualitative content analysis. This determined whether the expression of students' needs was consistent and whether the intended measures promoted the consideration of needs. The students' statements suggest that the manifestation of the desire for a particular need to be considered is differentiated at different times. Furthermore, students make differentiated statements during the interviews regarding the desired consideration of needs.

During the interviews, the students mentioned the varied and hands-on tasks as positive aspects of the lessons. Furthermore, the pupils positively emphasized the perceived freedom of choice through the different solution paths. The teaching methods used to satisfy the need for competence were recognized by the students. Particularly hands-on tasks were emphasized by the students and underlined by the desire to expand their own procedural knowledge. In this way, the students explicitly demand the experience of competence - also in real-life situations. In addition, the students say that longer periods of reflection would increase their experience of competence. The cooperative and pedagogical forms of playful learning were designed to satisfy the need for social relatedness. These forms of learning are evaluated differently by the students. Most students describe the collaborative activities as enriching and successful. However, two students limit the successful characteristics of collaborative learning and express the wish to work individually more often in subsequent learning sessions, as there was no collaborative learning within the group. This shows the importance as a teacher of constantly reflecting on group collaboration. It also shows that simply offering a needs-based arrangement is not enough to meet students' needs. This shows that individual, contextual and institutional influencing variables control the consideration of needs (Helmke *et al.*, 2007).

Implications that can be described for the actions of (prospective) teachers include an appreciative attitude and commitment to all students as constitutive characteristics of needs-based teaching. In the unit described, the appreciative attitude is conveyed through the experience of attention. However, the constructive discussion of the students' tasks and solutions and the resulting support show the appreciative attitude of the teachers. In addition, feedback and guidance are essential features that a teacher should establish in his/her teaching to respond appropriately to students' needs and to facilitate inclusive learning.

The feedback given to students during the learning process should be formative assessment and feedback that allows students to adapt their learning strategies and draw conclusions for solving the task (Haase, 2017). On this basis, advice that is targeted to specific issues and can be used in a sustained way has also been shown to be effective (Hattie, 2014).

Taking these characteristics into account, feedback and counselling can promote students' self-efficacy (Haase, 2017). To implement these characteristics in the classroom, focused preparation using the characteristics of needs-based teaching described above as guiding principles is essential.

Thinking ahead – integrating modes of representation across a spiral curricular structure

According to Bruner, people actively construct meaning for themselves, considering cultural resources and social interaction. In addition, the consideration of psychological development makes it possible to discuss a multidisciplinary content (Bruner, 1971). This principle also characterizes the educational intervention carried out. It is designed as a spiral curriculum to ensure that it can be linked to the cognitive abilities of the students (Bruner, 1976). The spiral structure of skill development is characterized by the fact that a learning object is first explored at a basic level and with increasing complexity later (Haste & Gardner, 2017). Along this spiral of complexity, both specific and interdisciplinary skills and ways of thinking are promoted according to the level of education (Gillen, 2013; Hardy et al., 2017). At the same time, the use of disciplinary language is sharpened (Plinz, 2021). These competencies are developed experientially and actively using different representational modes (Hardy et al., 2017; Haste & Gardner, 2017). Bruner establishes the enactive, symbolic and iconic form of representation for intellectual growth (Haste & Gardner, 2017). Each form has its own way of representing processes (Bruner, 1971). While knowledge through the enactive mode of representation is gained through one's own actions, the development of knowledge based on the iconic mode of representation is characterized by reference to images and graphics (Käpnick & Benölken, 2020). Finally, knowledge acquisition through the symbolic mode of representation is characterized by the acquisition of knowledge through different symbol systems, such as spoken or sign language (Käpnick & Benölken, 2020). Bruner emphasizes that different modes of representation should be aligned with cognitive and psychological development. However, they do not build on each other sequentially, so that the ability to visualize a product of action does not mean that the actions to achieve the product can also be performed (Bruner, 1971). Based on Bruner (1971), Gebauer and Simon (2012) identify two further basic levels. The communicative-interactive mode is intended to provide access to the environment through media such as the body and spoken language or prosody (Gebauer & Simon, 2012). The sensory development of a learning object takes place through sensory experiences such as touching, feeling or smelling and refers to the Montessori method (Gebauer & Simon, 2012). This expansion of modes of representation offers further potential for inclusive 'science education'. The development of learning objects on the different modes provides opportunities for all students to connect and ensures student participation in common learning objects (Feuser, 2011). This is supported by the optional use of different modes of representation (Gebauer & Simon, 2012), so that the programs can be selected according to individual needs. The choice of representation is not based on age, but rather on education and experience (Haste & Gardner, 2017). In this way, different cognitive and emotional stimulation can be achieved in students, and students become constructors of their individual learning process (Blumberg & Mester, 2017; Lipowsky, 2021). These theoretical principles are fundamental to the conceptualization of the tested instructional interventions. Along the spiral curriculum, the three learning processes are addressed: 1. acquiring and refining knowledge, 2. transforming knowledge to use it for new tasks, and 3. evaluating whether the transformation is appropriate for the intended purpose (Bruner, 1976). Different modes of representation are used and – as already noted by Bruner (1971) – interacted with each other. This interaction is illustrated in the model of "spiral curricular linking of modes of representation in interaction".

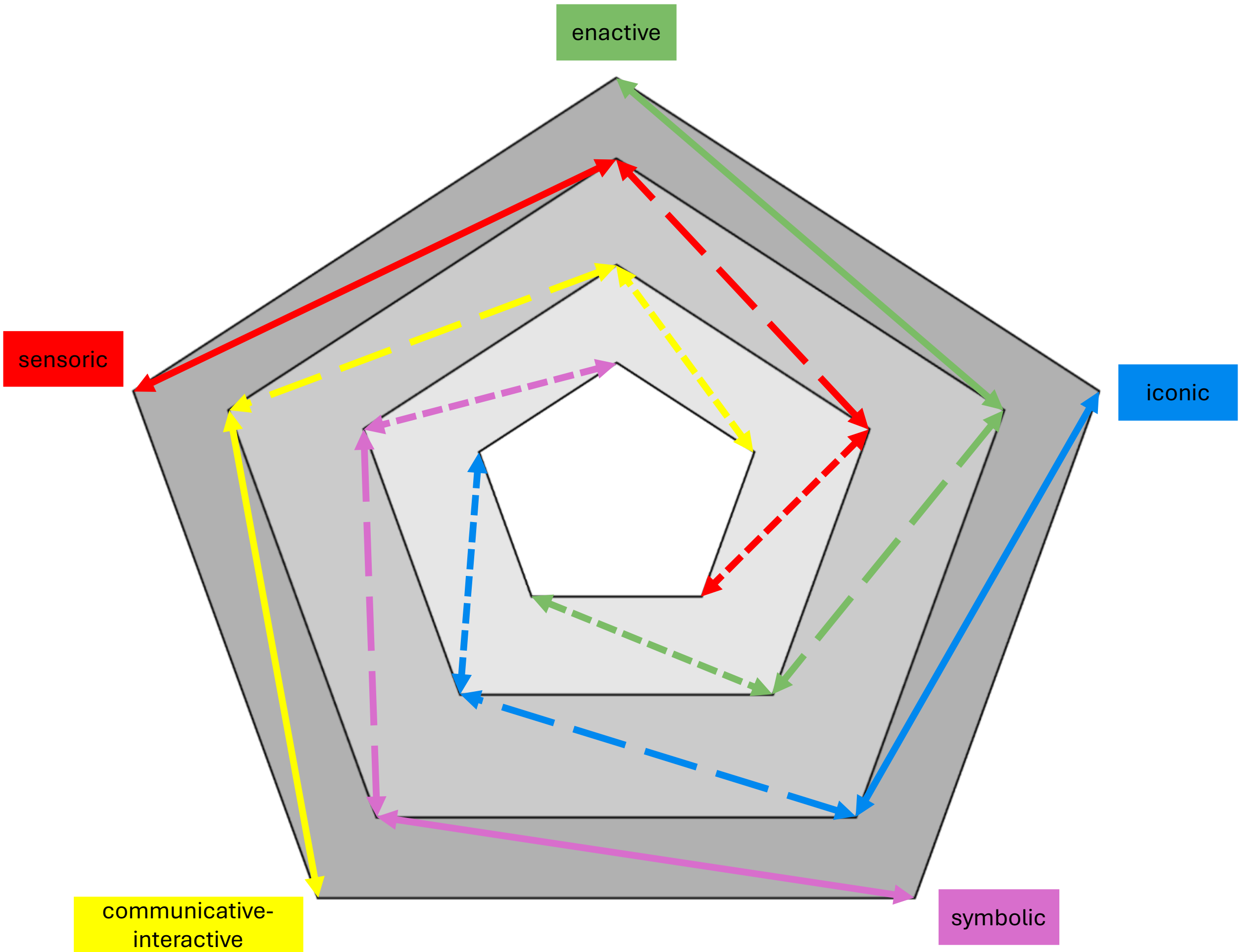

Figure 4: "spiral curricular linking of modes of representation in interaction" (Schröer et al.)

The model brings the five modes of representation of education together and illustrates their possible spiralling interrelationships. The levels of representation 'communicative - interactive', 'symbolic', 'sensory', 'iconic' and 'enactive' are labelled at the corners of the outer pentagons. The continuous colour coding of the arrows and circles makes it clear where each mode is represented in the model. The arrows connect the different levels of representation. The model shows that one form of representation can be linked to any other form. Within these links there may be quantitative differences in the number of linked representations. The levels of representation can be related to each other, and a change of representation is always possible in all directions. The spiral arrangement in the model illustrates that a spiral curricular acquisition of knowledge (Bruner, 1976) can be supported using different modes of representation in combination. The use of different modes of representing a learning object enables challenging learning on a common object (Feuser, 2011) for all students. The model of 'spiral curricular linking of modes of representation in interaction' shown in Figure 4 serves to illustrate the reciprocal linking of modes of representation across subjects and topics. This model can be used to sort educational tasks thematically and to evaluate the modes of representation involved. The multidimensional structure (see Figure 5) is added to the model to make the direct links between the modes of representation more concrete. In addition, teaching and learning arrangements are possible in which more than two modes of representation are combined in a pedagogically effective way. Figure 5 describes examples of different combinations of two modes of representation. For example, the "communicative-interactive" mode can be linked to the "symbolic" mode by transferring *verbal commands* that a learning robot or microcontroller is to execute to *symbolic programming language*. A quantitative extension of the examples in terms of the number of representation modes included is possible, but not intended at this point.

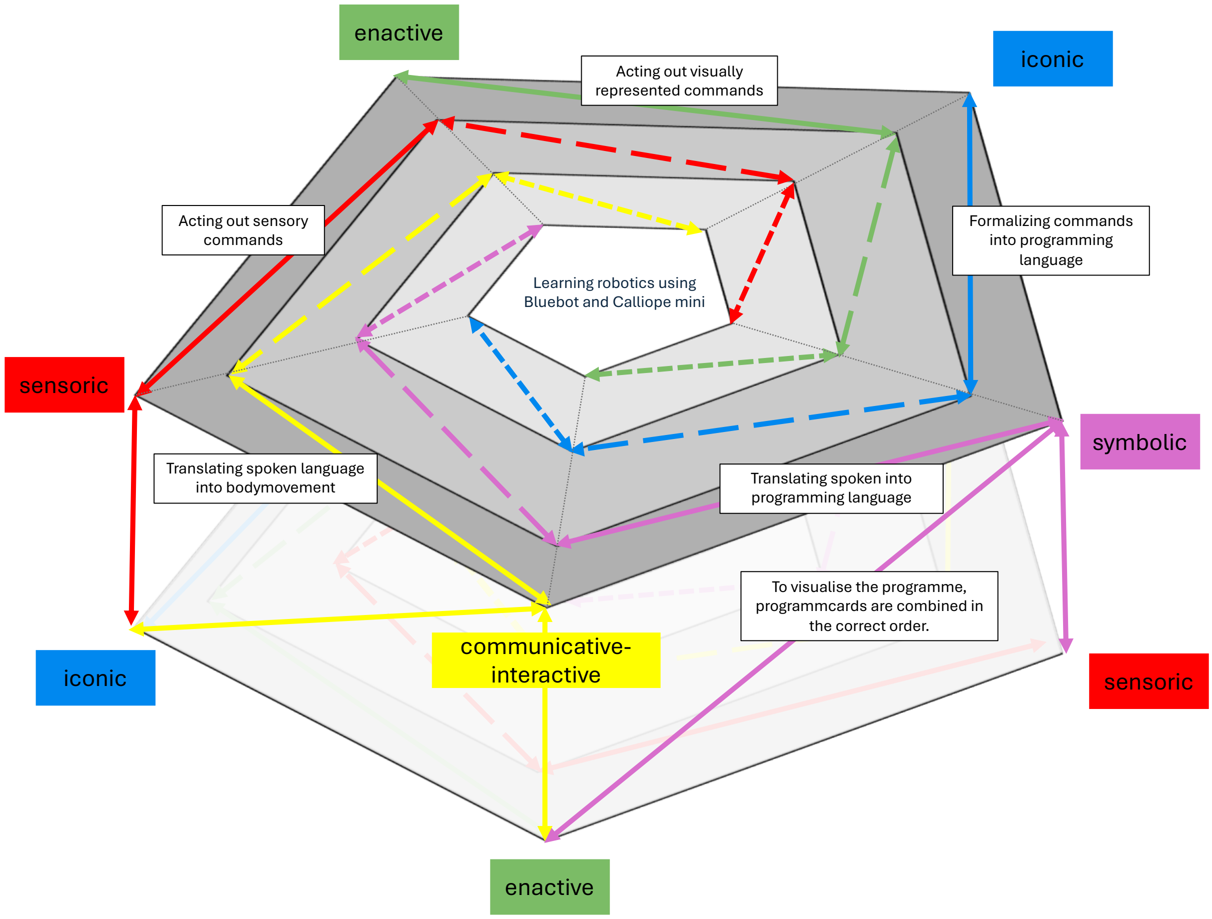

Figure 5: Exemplary linking between the modes of representation using the example of a spiral-curricular digital-technical education (Schröer et al.)

The combination of the different modes of representation, theoretically in the model and practically in the teaching situations, shows that the combination and use of the different modes of representation enables all pupils to participate in the object of learning. The differentiation of the level of abstraction makes it possible to switch between the modes of representation. In this way, students who use a supposedly more complex form of representation and students who use a supposedly less complex form of representation can exchange knowledge.

During the lessons in which the BlueBots™ learning robots are used, the students' actions as well as the presentation of the information on the worksheets are primarily assigned to the enactive and iconic modes of representation. The iconic images of the symbols on the tasks are identical to those on the BlueBot™ buttons. This allows students to make a direct connection between the iconic representations. The solutions are designed to be enactive, as the problems are tested and evaluated with the learning robot. The worksheets are designed so that the solutions can be documented in diverse modes. The design of the task description focuses on reducing the amount of written language and supporting comprehension through iconic representations. This creates the first moments in which different modes of representation are combined. Furthermore, the modes of representation are linked when, for example, the students visualize a program by first arranging symbolized programming commands in a chain of commands. Overall, the teaching intervention is designed with a special focus on communicative interaction between the students and helps to encourage them to engage in dialogue. This can be noticed, for example, when solutions are discussed, evaluated or adapted.

In addition, Computational thinking skills are also organized in a spiral curriculum in the teaching arrangements described. The use of BeeBots™ is already possible at pre-school level in order to introduce skills such as questioning or first if-else connections (Ministry for Children, Family, Refugees and Integration of the State of North Rhine-Westphalia/ Ministry for Schools and Education of the State of North Rhine-Westphalia, 2018). This topic has not yet been tested in our research group. For this reason, this part of the spiral curriculum teaching concept is not reflected at this point.

It can be followed by learning arrangements with BlueBots™ and possibly other learning robots in school years 1 and 2. Building on the pre-concepts, the competence domain of Computational thinking should be improved. The BlueBot™ can be used to solve path problems. The path problems are conceivable in different contexts, such as in Figure 6: 'BlueBot™ as a bus driver'.

Figure 6: 'BlueBot^{TM} as a bus driver' ©Schemel (2023)

Students must first recognize and understand the problems presented (Wing, 2006). Students then need to devise and program different steps to solve the problem in a way that encourages algorithmic thinking (Wing, 2008). Decomposition into sub-problems or abstraction of the given information may also be necessary (Barr & Stephenson, 2011; Hong, Qian & Yang, 2021). For example, if students are asked to deliver parcels to different houses in the 'BlueBot™ as a parcel deliverer' task, considering a delivery route individually as a subproblem may reduce the complexity of the problem. However, the BlueBot™ can also be used to promote the reflective consideration of an individual algorithmic product as well as the identification of errors and their solution (Hong et al., 2021). In school years 3 and 4, these skills can be further developed using the Calliope mini™ microcontroller.

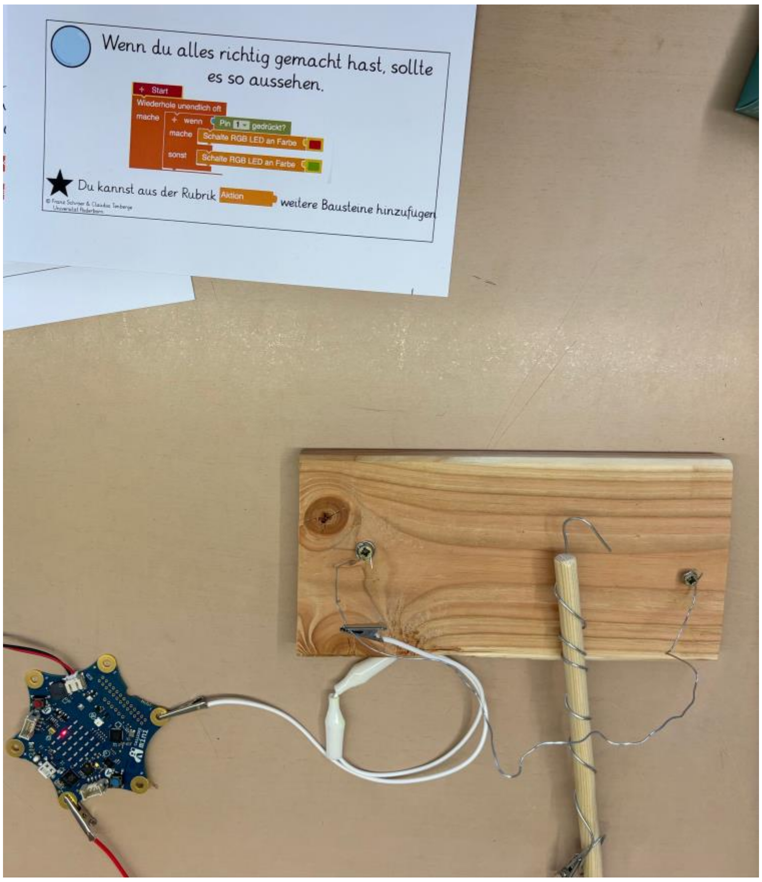

Figure 7: Calliope Mini as hot wire ©Schneider (2024)

The lesson is designed in such a way that the individual stations are first presented verbally and in a linguistically sensitive way using the communicative-interactive mode of representation. Furthermore, the symbolic mode of representation is considered when, for example, illustrations are linked to the written presentation so that the iconic and symbolic modes of representation are accessible. This linking enabled students to reread and repeat technological terms and relevant representations. Overall, the symbolic mode of representation is particularly important when working with the Calliope mini™ because the programming blocks must be represented and linked symbolically. This written representation of the programming blocks means that reading skills become an essential pre-requisite. This is linked to the communicative-interactive dimension when, for example, different verbally expressed programming steps are translated into symbolized programming blocks. The inclusive design of the lessons enables all students to participate by supporting each other within the individual competencies of each student. The active, digital-technical way of working provides an enactive approach to the subject and opens further opportunities for participatory involvement in the lesson. The Calliope mini's various sensors allow it to be used in a variety of ways, for example, as a sensory representation through the acoustic output of different sounds. During the lesson, students are given hint cards to actively construct their own knowledge. These cards include images and provide access to the subject through the iconic form of representation.

Computational thinking skills already acquired are used and further differentiated along the spiral curriculum. The range of skills is broadened by using the Calliope mini™ and block-based programming. The problems of other concepts need to be identified and understood through the systematic processing of information (Wing, 2006, 2008). The previously acquired competencies form the basis for the specification of digital-technical competencies. In addition, students learn a new, block-based form of algorithmic solution methods and increase their ability to deconstruct problems and solve them algorithmically. Furthermore, more differentiated and complex errors and their identification and solution become possible (Hong et al., 2021). This increase in complexity arises, for example, from the Calliope mini's multiple sensors and actuators, and realizes the theoretically described spiral curriculum of Computational thinking skills in the classroom. In addition, it allows for connectivity to further specify Computational thinking competencies across educational levels in lower secondary school.

Therefore, it can be concluded that both the *modes of representation* and the *content-related Computational thinking competencies* can be built up in a spiral curriculum in the intended teaching arrangement and can provide a link to lower secondary level.

Conclusion - Challenges for professional development

This article examined the urgency to further establish digital-technology education and prepare teachers professionally for this school practice. Various concepts of teaching and learning are reflected from three perspectives and the challenges of linking theory and practice are examined. The results can be regarded and discussed against the background of the guiding question: "What are the effects of linking theory and practice on the education, self-efficacy and professionalization of (prospective) teachers in digital-technical 'Sachunterricht'?

The results show that the role of the (prospective) teacher in inclusive digital technologies 'Sachunterricht' is crucial to a successful implementation. Teachers must integrate both their content and pedagogical knowledge into the planning and implementation of technology education lessons. Particularly regarding a perspective towards inclusive education, it becomes evident that a meaningful pedagogical approach is important to do justice to the individual needs and potentials of *all* pupils. The reflexive analysis of the lesson illustrates the heterogeneous characteristics of the implementation of an inclusive lesson. The results show that an increase in learning can be achieved for all pupils and that pupil participation increases.

Against the background of the article's guiding question, the problems that arise in connection with the theory-practice connection were to be analysed and adapted. The central difficulty was that dealing with teaching materials can be challenging in comparison with dealing with analogue learning materials. In addition, the indispensable literacy development of the content makes it difficult to use the Calliope mini™. The disadvantage of pupils with lower literacy skills needs to be reduced by language sensitive characteristics of the learning environment. So that all pupils can participate in a common learning object, such as following the codes. To this end, alternative colour patterns can be used as a support measure.

To be able to meet the demands of inclusive technology education 'Sachunterricht', prospective teachers need theoretical background knowledge. Training and seminars offer opportunities to develop digital literacy and to build this knowledge. Seminars in a university context combined with micro-teaching elements promote the development of individual competencies. The theoretical background knowledge acquired, and the experience gained in teaching can be used for topics and ideas for empirical final thesis’s and thus be examined in greater depth. In terms of evaluating the effectiveness of the measures, these positive effects show up in terms of the increase in teachers' skills. The subjective assessment of the students also suggests that the lessons can promote motivation and interest in technological problem-solving. Further empirical research on students' motivation, interest and competence growth in technological problem-solving can be justified accordingly.

Regarding the question "To what extent does the theory-practice connection affect the professionalization of (prospective) teachers?", it can be stated that the lessons carried out effect the self-worth of (prospective) teachers and can positively influence it, thus contributing to the professionalization of the teacher. It can help to anticipate *“stumbling blocks”* and difficulties for future learning units and to better assess the necessary specialized knowledge for technology education in a digitalized living environment.

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