Technology Education considering children's needs – Evidence-based development of Inclusive materials for learning with robots at primary level

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ABSTRACT

The developmental task inclusion effects the design of teaching and learning regarding technology education at primary level. National studies have addressed the issue and have devoted efforts to theory-based development of conditions for inclusive education and their empirical substantiation (Schröer & Tenberge 2022).

In German primary schools the subject '*Sachunterricht'* includes among other domains technology education. An essential field of research is shaping the developmental task inclusion in the context of technology education. However, narrowing down the concept of inclusive education for the multiperspective school subject '*Sachunterricht'* is complex (Seitz 2018). The use of potentials and consideration of individual needs is one distinguishable context when conceptualizing inclusive education in '*Sachunterricht'*.

The consideration of needs in classrooms can be substantiated based on the theory of basic needs (Krapp 2005). Research demonstrates that problemsolving activities with varying degrees of self-direction take different needs into account (Beinbrech 2003; Tenberge 2002). However, the design and substantiation of learning settings, that regard to pupils needs, have so far been largely omitted by research.

This justifies the idea of the presented research project. Based on the theory of basic needs, rooted in developmental psychology (Ryan & Deci 2018), a set of problems and tasks for problemsolving with the learning robot *Bluebot*™ was developed. Learning settings were tested in classrooms and evaluated in a first cycle to adapt them based on evidence. Preliminary findings of pre-post comparisons show effects on problemsolving skills and self-efficacy.

The present article falls into five sections of which the first one will define the fundamental concepts addressed. After substantiating the requirements of inclusive technology education and technological Problemsolving, section three will introduce the adaptive set of tasks for technological problemsolving at primary level. Based on the methodical framework in this section, findings from the first cycle of a design-based-research project are presented and discussed.

Key Words: Technological Problemsolving, Inclusion, basic needs, learning robots

1. INITIAL SITUATION

In a world permeated by technological artifacts, problems, processes, and values, capabilities related to the use, construction, invention, and disposal of technology are fundamental for responsible participation. Under the assumption of a constructivist approach to teaching and learning (Möller, 2012) the objective of technological literacy has been adopted in educational systems all over Europe (De Vries, 2018). Therefore, technological literacy shapes the nature of learning objectives, contents, and methods.

Considering, the idea of an inclusive educational system, conceptions, methods of inquiry, and goals of technology education have to be reconsidered in modified circumstances (Schröer & Tenberge, 2023). School subject related research for education at primary level in Germany has taken up the issue and devoted some effort into the development and redesign of teaching and learning under inclusive requirements.

1.1. Theoretical Framework - Technology Education at Primary Level in the german educational system

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’. Since the common translation into ‘interdisciplinary science and social studies in primary education’ does not mention the technology education part of the subject, the German term is adopted for a precise description of what is meant in the present article.

One fundamental idea of ‘Sachunterricht’ is to stimulate children’s learning about their environment from a variety of different perspectives of which a technological perspective is one. This principle is addressed to as multi-perspectivity (Thomas, 2015). It implies that one can learn about an artifact or a phenomenon from various perspectives. The perspectives addressed in teaching and learning arrangements are then iteratively related to different areas of inquiry and bodies of knowledge (Köhnlein, 2012). Following this argument, the coexisting conceptions of ‘Sachunterricht’ are shaped by three fundamental categories.

(i) Children with their different preconceptions, interests, ideas, questions, and needs (Fölling-Albers, 2015)
(ii) Living Environment with the areas in which children act, which they explore and in which they have experiences (Nießeler, 2015)
(iii) (scientific) domains with their bodies of knowledge, methods, and processes of inquiry as well as the nature of science and technology (Köhnlein, 2015)

Accordingly, Technology can be thought of as a scientific domain as well as a section of one's living environment. Regarding children as a determinant to the design of teaching and learning, Mammes (2001) states that children are often interested in how technological artifacts are constructed, used, or disposed. Referring to Erikson (2003), Tenberge (2002) ascribes a kind of sense to create to children, especially those of young age. Therefore, several theoretical approaches to principles of technology education at primary level emphasize a combination of hands-on and minds-on learning activities as a productive way to explore technology (Möller, 2015).

1.1.1. Learning objectives

As mentioned in the outline, the main goal of technology education at primary level is to enable students to participate in a society that is permeated by technology.

Based on hands-on and minds-on learning activities, fundamental sections of learning objectives under the literacy theorem are the analysis of technological functions, the understanding of the impacts of technology, the communication of technology, and the comprehension of connections between technology, economy, and science (Möller, 2021).

1.1.2. Contents

The identification of relevant and enduring content for technology education at primary level becomes more complex under the conditions of an increasingly complex and inscrutable nature of technology and fast development of technological innovations.

Federal states in Germany have revised their policy curricula in recent years and often included content elements linked to requirements of digital technologies in children's learning environment. The binding curriculum for the federal state of Northrine-Westphalia added the simulation and description of the principle of input, processing, and output to the contents for 'Sachunterricht' (MSB NRW, 2021). The media literacy framework established through federal policy emphasizes the identification, understanding and reflection of algorithmic patterns in different contexts as an area of learning at primary level (MSB NRW, 2020).

Subject related research as a distinguishable area from educational policy does as well formulate and substantiate content areas for technology education. The predominant focusses here are on the stability technical structures, the functionality of tools and machinery, the construction, functioning and propulsion of vehicles, the utilization of natural forces and finally the comprehension of important inventions of mankind (Möller, 2021).

1.1.3. Methods

Unlike the natural sciences with their causally oriented mode of inquiry, technology is characterised by a final orientation (Möller, 1998, 2021). Therefore, methods of technology education relate scientific laws on the one hand to the social side of technology on the other (Mitcham, 1994; Ropohl, 2009). Technological problemsolving uses this principle of inquiry to create, construct, optimize, and dispose technology. Studies reveal that problemsolving skills such as the recognition and localization of a problem, the development and testing of a solution, and finally the evaluation and reconsideration of a problem can be promoted at primary level (Ahlgrimm et al., 2018; Beinbrech, 2003; Mammes & Zolg, 2015).

1.2. Problem Outline - Technology Education under the demands of Inclusion at primary level

Based on the ratification of the UNCRPD in Germany, the reform issue of inclusion is associated with requirements for the transformation of schools, education, and society at different levels (Trumpa & Franz, 2014). The intention of inclusive education is to further develop teaching in the direction of reducing barriers to learning for all children and considering different prerequisites (Booth & Ainscow, 2016; Grosche, 2015). Therefore, the focus here is on microstructural considerations for the further development of teaching under inclusive demands (Trumpa & Franz, 2014).

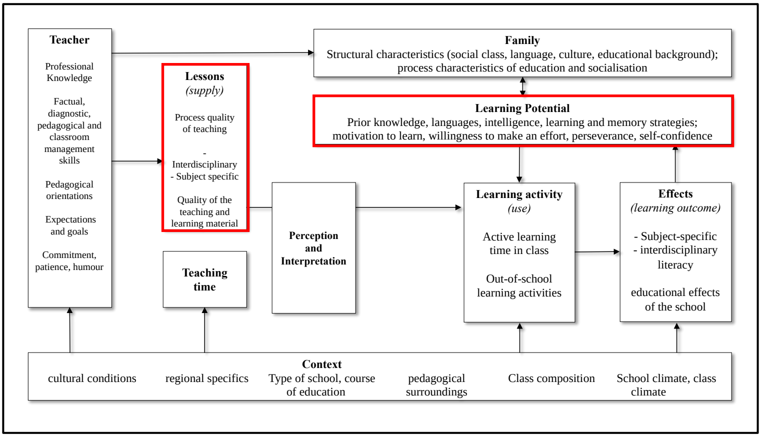
To identify a specific starting point, one must first ask the question, which sub-areas of teaching and learning must be reconsidered under the requirement of inclusion. According to Schröer and Tenberge (2022) the design of inclusive 'Sachunterricht' forms a cross-sectional task that affects the design of teaching and learning in task design and arrangement. Educational research in Germany is permeated by the use of different understandings of inclusion (Grosche 2015). Therefore the little amount of empirical studies on the design of equal and adaptive teaching and learning environments are often hard to put into comparison as they use varying degrees of focus on children affected by marginalisation and varying personal attributes inducing marginalisation. For the development and evaluation of the inclusive learning environment for technology education in this paper, we utilized a definition of Inclusive education focussing on an assumed wide heterogenity of learning individuals' potentials and needs in a classroom regardless of their predetermined personal attributes, such as gender, race, cultural background or (dis-)ability. In this respect, 'Sachunterricht' in general and technology education, in particular, with its hands-on and minds-on approach to learning, are considered to hold certain potentials for the design of inclusive teaching (Hinz, 2011). The basic principle of adaptive teaching has been identified as a reasonable approach to address the assumed heterogenous learning prerequisites of pupils (Simon, 2015). However, the outlining of the prerequisites of pupils is carried out under different theoretical presuppositions. Pupils are described in terms of their preconceptions and abilities (Möller et al., 2006), their preferred sensory channels (Gebauer & Simon, 2012) or, as in this case, their diverse kinds of needs (Schröer & Tenberge, 2021). National and international research and educational policy has so far repeatedly emphasized the relevance of needs (Ainscow, 2007; Feuser, 1989; Schumann, 2009; Simon, 2015), yet still they are rarely integrated into the development and design of inclusive 'Sachunterricht' (Schröer & Tenberge, 2022).

1.3 Suggested solution - Adaptivity as a framework for an inclusive task design

According to Helmke (2021) the interdependence of teaching and learning from a constructivist standpoint can be described in a model of supply and use. The model contains of external entities to the individuum and internal preconditions that determine each other in a complex way (Fig. 1).

Adaptive learning environments place particular emphasis on the optimal use of learning opportunities by all pupils with their individual learning potential (Hardy et al., 2011; Simon, 2015). This paper highlights especially pupils' needs that form one sub-area of their learning potential. A great variety of different ways of using and delivering lessons can be assumed, as the sub-areas of the model are interdependent (Helmke 2021, p. 71).

Figure 1.
A supply-use model of the impact of teaching (Helmke 2021, p. 71 – translation by FS)



Therefore, our basic assumption is that offering pupils adaptive task formats reacting to diverse expressions of the needs for autonomy, social relatedness, and experience of competence, based on the theory of basic psychological needs (Ryan & Deci, 2018), meets fundamental requirements of the design of inclusive 'Sachunterricht'. This approach intends to address the diversity of supply and use in relation to the different needs of students (Schröer & Tenberge, 2021).

In addition, our assumptions are driven by the specific way of designing and arranging tasks for 'Sachunterricht'. According to Fischer (2014) task formats should allow not merely the transmissive replication of culture, but also, it's transformation and renewal. Our approach looks at tasks in isolation, but also integrates other basic features of 'Sachunterricht', such as learning in the zone of proximal development and scaffolding (Möller, 2012; Vygotskij, 1978). Nevertheless, the tasks are emphasized in this article as they are considered to hold potentials for the design of inclusive teaching and learning (Lütje-Klose, 2013) and were therefore used as a starting point for the adaptation of teaching.

According to the arguments, the following two research questions can be derived:

(i) How can an adaptive set of tasks be designed that can take diverse expressions of pupils' needs for autonomy, social relatedness, and competence into account?

(ii) What are the learning outcomes in terms of problem-solving skills and self-related cognitions (interest, self-efficacy, experience of competence) of lessons adapted based on the tasks designed?

According to Schomaker (2019) the design of inclusive teaching cannot be achieved by redesigning tasks and methods alone. The question of the contents for inclusive education of the subject 'Sachunterricht' must be dealt with under changed preconditions as well. So before dealing with research procedures and methods to find a humble answer to the questions above, the following chapter will describe and substantiate the technology related content for the lessons designed.

2. PROMOTING TECHNOLOGICAL PROBLEMSOLVING WITH LEARNING ROBOTS

The diverse environments children grow up in are increasingly permeated by digital technological artifacts and processes (Blümer, 2019; Goecke et al., 2021). Kids although of young age play with digital toys and use digital tools daily.

In recent years everyday activities are being performed more and more by robots, i.e., "independent" mobile machines that can carry out a pre-programmed task in a defined environment. These robots can usually be described in terms of elements of input, processing, and output. They contain sensors, processors, and actuators. However, robots are in almost every case designed as so-called black boxes, meaning their way of functioning is not apparent. Through their seemingly self-determined "behaviors" but also through malfunctions or the completion of more complex tasks, they spark the interest not only of children. As the jobs robots perform become increasingly fundamental and complex through higher computing performance and machine learning functions, the importance of a basic understanding of how robots work increases.

To promote basic understandings of how robots work, e.g. the unambiguity of commands, the principle of input, processing and output, and the translation of everyday language into programming language and vice versa are of importance. By implementing this content, it is hoped to promote participation in a robotized society and computational thinking skills for all children.

3. METHODS AND PROCEDURES

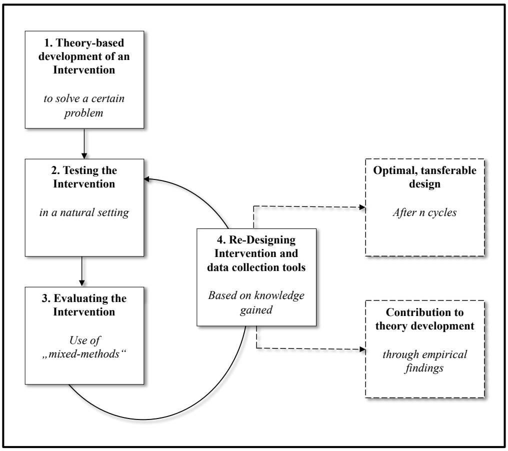
So far, existing materials for problem solving with robots or programmable learning materials are often designed in a strongly instructional way in the first access due to their complexity. Hence, they only partially meet the requirements for hands-on *and* minds-on learning activities. Considering the requirements of inclusive teaching, learning materials on the subject often require learners to have strong language skills. The existing materials that only require basal capacities are often designed as gaming and therefore from a technological perspective non-finally oriented.

Hence, in our project we designed an own set of materials and tasks using the learning robot *Bluebot*™. It is especially designed for educational purposes at elementary and primary level.

Figure 2.
Bluebots and task formats (by Till Verch)

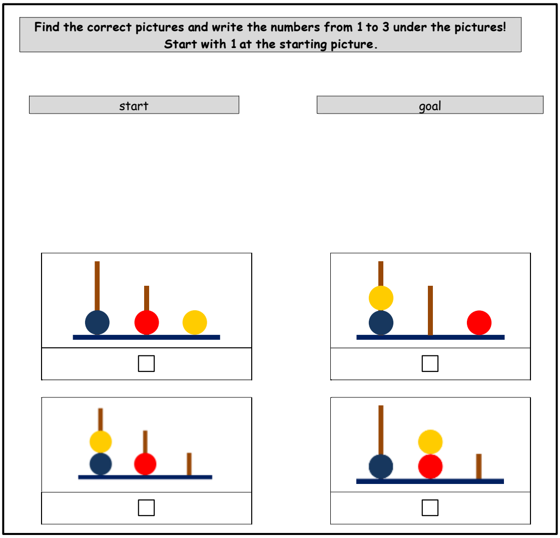
Located in the methodical framework of Design-based-research (Gess et al., 2014; Reinmann 2005), we created a set of tasks (see chapter 4.1) and materials under the theoretical requirements of inclusive education and basic psychological needs theory (Fig. 3 ad 1). It is designed so that teachers can adapt it to different expressions of pupils' needs. The tasks therefore include different degrees of freedom, can be tackled in different social forms, and are designed in such a way that pupils can adjust the level of difficulty autonomously.

Figure 3.
Procedure of Design-based Research (Gess, Rueß & Deicke 2014, p.12 – translation by FS)



The presented learning setting was explored and tested with a seminar course of pre-service teachers in the winter term of 2022. After adaption of the materials to the target group of primary school pupils (n= 71) the planned lessons and materials were tested on two project days in three classrooms in a primary school (Fig. 3 ad 2). The lessons were evaluated in a first cycle by collecting quantitative data about the promotion of problemsolving skills, situational interest, and self-efficacy, with yet established instruments (Bohrmann, 2017) (Fig. 3 ad 3). The pupils were tested on their development of content-independent problem-solving skills with a revised version of the Tower of London for group testing (Fig. 4).

Figure 4.
Item 1 – Tower of London group Test for the assessment of problemsolving skills (Bohrmann, 2017, p. 341 – translated by FS)



Data on situational interest (e.g. "I really want to learn more about problemsolving with robots."), self-efficacy (e.g. "I feel confident to answer difficult questions about robots.") and experience of competence (e.g. "I know a lot about robots.") were collected by written survey using a four-point Likert scale (Bohrmann, 2017, pp. 408). Further data was available e.g. in the form of pupils drawings, but were not systematically collected. Accordingly, these data sets are used here for illustrative purposes only.

The first testing of the intervention was conducted under exploratory purposes. Therefore, no control group was included in the sample. Hence, for the evaluation of the quantitative data descriptive evaluation methods are used to a large extent. The pupils were informed that participation was voluntary. All pupils had a declaration of consent for participation from their legal guardians.

4. FINDINGS – DESIGN AND EVALUATION OF AN ADAPTIVE TASK SET

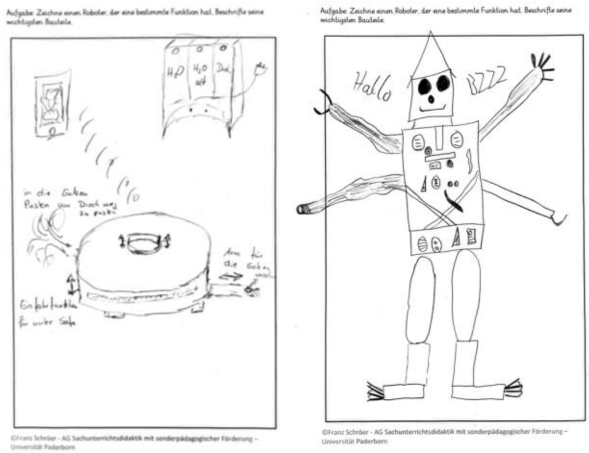
The basic idea of combining transmissive and transformative tasks was redeemed by using plugged and unplugged learning supplies. The two unplugged tasks presented in the following chapter intend to introduce the topic of robots and how they work. They stimulate contexts in which robots do not yet exist. The *plugged* examples presented afterwards tend to be more transmissive in nature. They address everyday contexts, where robots already do exist or are easy to conceive.

4.1. Unplugged supplies for learning about robots

One introductory task is to program the teacher first and a classmate afterwards. The objective is to stimulate a basic understanding of the unambiguousness of commands. Contexts addressed are e.g., putting on a jacket or pullover by voice or written commands, brushing teeth or drinking a sip of water. Some pupils used the supply to develop their own contexts for example putting on, taking off a schoolbag or opening and shutting a pencil case.

Another unplugged task is drawing a robot with a function of one's own devising. The outcomes of the task are characterized by extreme diversity. Similar to the research by Müller and Schulte (2017), the drawings show both humanoid robots with simple or complex abilities but also transmissive drawings of robots from the children's living environment, e.g. cleansing roboters (Fig. 4). The task could be extended to include, for example, the labelling of components or an oral explanation of the functions. For raising data about children's preconceptions about robots they were asked to write down useful components of a homework robot.

Figure 5.
Two different robot drawings



4.2. Plugged tasks for learning about robots using the learning robot Bluebot™

The Bluebot™ learning robot can move forwards and backwards and perform 90 degree turns. According to the manufacturer, it can store 200 commands and execute them consecutively. Via Bluetooth connection it can be programmed block based as well.

To ensure sufficient complexity of the tasks we used a map of 24 squares (6x4) the Bluebot can be moved on. To get used to the basic functionality, pupils solve several simple start-finish tasks at first, where obstacles, interim targets, or restrictions (e.g. robot can only turn left) can make finding one solution, an optimal solution or several solutions more difficult. By using sticky-notes tasks can easily be adapted or modified by the pupils themselves.

When the pupils are familiar with the functions, they can move on to problem-solving tasks that borrow elements from their living environment. The tasks often require the combination of real-life and logical technical requirements.

4.2.1. A robot for postal services

In the postal-service task the pupils are asked to place several houses and a post-office on the map and deliver a defined amount of mail to the houses on the shortest way possible. The level of difficulty can be adjusted relatively easy by the placement of the objects. As the pupils progress in the task, the optimal placement of the post office becomes a virulent problem as for example parcel delivery stations are often located in peripheral, but a logical placement would rather be in the middle of the map. In this way, different areas of demand on technological processes can be illustrated and discussed. During the task, it is often discussed what other functions the Bluebot™ would need to be a good postman. Here, there are learning opportunities to talk about actuators and sensors, for example.

4.2.2. A school bus robot

A more structured context used is to program the Bluebot as a school bus robot where the starting point of the bus, the school building and several traffic lights are pre-defined. Again, pupils often argue about different requirements for the optimal route to take. A common issue here is whether the school bus is only using main roads or side roads as well.

4.2.3. A robot for vacuuming and mopping

Where is the optimal place to start when navigating all over the map? A fundamental question for this task is where the best place for the charging station is and how all fields of the map (i.e. the whole room) can be cleaned. Mopping is restricted by the additional condition that the water tank must always be refilled at the charging station after ten mopped fields. This leads to the question how passing fields already cleaned can be avoided and whether there is a solution, where no field must be crossed twice. Again, logical, and real-life requirements come into play as in real-life charging stations are not placed in the middle of a room. As the chains of command become very long, this task is a good opportunity to talk about further requirements for a cleaning robot and how linear command chains are not sufficient for every type of requirement.

4.2.4. Two robots dancing

Programming two robots in a synchronous or exactly asynchronous way requires precise agreements among the students and good communication in the team. A sequence of dance steps can be varied greatly in complexity and the pupils can decide autonomously, how a dance pattern should be arranged.

4.2.5. A robot doing whatever

In a final task-format the pupils are asked to design their own task for the others in their class. Therefore, they first design the task one possible solution and learning supplements such as symbols for the map. As the creators of a task act as experts, peer-to-peer learning is promoted and the need for social relatedness can be considered in a comprehensive way.

4.2.6. On the reflexive engagement

In addition to reflection on the functional principles and components of robots, the tasks presented also provide the opportunity to stimulate discussion of strategies in the sense of problem-solving and computational thinking. Furthermore, participative, and social structures in class can be looked at retrospectively and, if necessary, transferred to other settings. There are further potentials in the use of more symbol-based programming environments, such as the micro-controller Calliope-mini™ or in the use of sensor-controlled robots, such as the Ozobot™.

4.3. Empirical Findings from the first lesson cycle

The sum value for problemsolving skills of the participating pupils changed from a mean value slightly below the arithmetic mean in the pretest ($M = 2.127; SD = 1.74; \alpha = .762$) to slightly above (*2.5*) in the posttest ($M = 2.953; SD = 1.98; \alpha = .870$). On average, the participants scored $M = 0.796$ ($SD = 1.405$) points higher in the posttest than in the pretest, whereby 5 points were the maximum possible in the test.

Since a uniform perception of the topic of robots in the subject ‘*Sachunterricht’* cannot be assumed for the pretest, the participants situational interest, self-efficacy and experience of competence were raised for the subject ‘*Sachunterricht*’ in general in the pretest and the topic of robots was integrated in the posttest. An overview of the descriptive results on self-related cognitions is presented in Table 1. One item had to be removed from the scale for situational interest due to lack of correlation with the construct (‘In the lessons I had to make an effort to listen.’)

Table 1.
Descriptive findings for self-related cognitions

Variable (number of Items)	**Pre-Test** Likert scale 1-4	**Post-Test** Likert scale 1-4
Situational interest (5)	M = 3.067 SD = .527 α = .636	M = 3.569 SD = .390 α = .683
Self-efficacy (5)	M = 2.963 SD = .726 α = .771	M = 2.991 SD = .646 α = .737
Experience of competence (7)	M = 3,179 SD = .732 α = .812	M = 3.396 SD = .448 α = .822

Also, based on repeated testing in other studies (Bohrmann, 2017), a satisfactory fulfilment of the statistical test quality criteria can be assumed. The data on situational interest are interpreted accordingly with caution.

4.3.1. Promotion of Problemsolving Skills

Since the research design did not include a control group, the comparison of the test scores in the pretest and posttest is based on the comparative mean value from Bohrmann's (2017) pretest (1.6502). Accordingly, a one-sample t-test was calculated. Table 2 shows that the mean value does not significantly differ from the comparative value in the pretest. The post-test mean value does differ from the comparative value on a highly significant level.

Table 2.
Significant difference in problem-solving skills Pre to Post

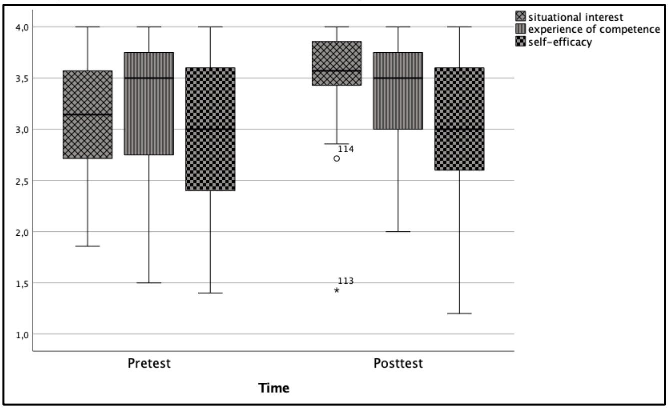
Variable (comparative value = 1.6502)	**T**	**df**	**bilateral p**
Problemsolving (pretest)	2,308	70	.024
Problemsolving (posttest)	5.266	63	<.001

Accordingly, the lessons are associated with a cautiously interpreted mean effect on problem-solving ability (*Coh.-d = .658*). Furthermore, a strong, highly significant correlation among pretest and posttest must be taken into account (*Coh.-d = .721**; p = <.001*).

4.3.2. Development of self-related cognitions

For the surveyed self-related cognitions, no comparative values could be adopted in advance. Accordingly, an effect of the lessons can only be hypothesized here. It can be assumed, that especially those pupils with a low experience of competence felt more competent regarding the topic of robots in the post-test as the bottom quartile decreases. This applies in a similar way to situational interest in the pretest to the posttest. However, the interval in which promotion takes place seems to be longer. For the pupils' self-efficacy, no significant promotion can be assumed (Fig. 5).

Figure 6.
Descriptive differences in self-related cognitions



5. DISCUSSION AND OUTLOOK

Based on the interpretation of the results, our research questions about the design of materials and the promotion of problem-solving skills and self-related cognitions can be answered as follows.

In essence, it can be assumed that the lessons are conducive to the problem-solving ability of the pupils, although the use of a control group and possibly a baseline is necessary for the coming cycles to be able to calculate test learning effects and other external effects.

A promotion of self-related cognitions can be assumed for the interest in the topic and the perceived own competence but not for self-efficacy.

It is open to what extent pupils with certain expressions of psychological needs benefited from the lessons. The expression of needs seems to be an additional variable in this respect. Alternatively, self-directed teaching settings could be compared in intervention studies, following the preliminary works of Tenberge (2002) and Beinbrech (2003) in another cycle. Targeted variations regarding the needs for experiencing competence and social relatedness also seem to make sense.

We see great potential in terms of researching pupils' preconceptions in the use of labelled or orally explained drawings of robots (Möller & Wyssen, 2018).

Finally, the observations that have not yet been systematized have led to the assumption that a targeted adaptation of language-sensitive learning supports (e.g. through pictograms) could be of interest. Particularly in the case of pupils with an already high level of ability, the development of challenging problems and the integration of further programmable teaching materials is still pending.

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