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Cross-Age Peer Tutoring Using a Design-Based Research Approach to Expand Computer Science Education in Schools

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ABSTRACT

In times of increased demand for the implementation of computer science as a compulsory subject in schools in Germany, additional human resources are required. These are reduced due to the shortage of skilled workers. The concept of "learning to teach" and cross-age peer tutoring enables older students to teach younger students, which has been shown to have positive effects on both groups. This approach is to be realized and evaluated in the "Minteers" project in order to develop a solution approach for lessons in computer science. Based on the design-based research approach, a solution for a concept in cross-age peer tutoring for schools is being explored. This is based on a preliminary examination of the conceptual foundations, followed by testing of the prototypes with the implemented didactic concepts. In the evaluation phase, the concepts and the materials are now being continuously developed and adapted.

Keywords: computer science education, cross-age, design-based research, peer tutoring, STEM

INTRODUCTION

Currently, and likely for the next few years, there is a visible and predicted need for STEM professionals in Germany, in part to strengthen companies (Anger et al., 2025). One way to address this need is through STEM education in schools, which requires teachers capable of leading these classes (Anger et al., 2025). At the same time, the subject of computer science is being given increasing importance in the core curriculum of German schools, as a comparison of the federal states shows (Ständige Wissenschaftliche Kommission der Kulurministerkonferenz [SWK], 2022). For example, in the 2021/2022 school year, computer science became a required subject for grades 5 and 6 in lower secondary school in the state of North Rhine-Westphalia (NRW) (SWK, 2022). The state is thus following the lead of other states in Germany (SWK, 2022). However, this implementation is facing obstacles. According to current estimates, there is a shortage of 32,000 computer science teachers, meaning that the recommended six weekly hours by the Standing Scientific Commission on Education Policy can only be realized as two weekly hours of computer science in lower secondary school (Gesellschaft für Informatik e.V. [GI], 2025a; Gesellschaft für Informatik e.V. [GI], 2025b; SWK, 2022). At the same time, there is a visible increase in the number of students, which further complicates implementation (Schröder et al., 2022). This necessitates an early examination of measures that could help alleviate the shortage of qualified personnel. At the same time, a way must be found to further strengthen the computer science education of students, which should be made possible by the successful implementation of the compulsory subject (SWK, 2022). To support the compulsory subject, the "Minteers" project is taking up the concept of cross-age peer tutoring. In this project, 9th-grade students act as tutors, teaching 5th-grade students. The tutors teach several students in groups in an AG format. “AG“ is the German abbreviation for “Arbeitsgemeinschaften” in which students of a school have the opportunity to participate in a voluntary project, which is outside the class in school (QUA-LiS NRW, n.d.). The "Satellitenlabore" has already implemented the use of cross-age peer tutoring for STEM education in schools, which this project builds on (Tillmann, 2025). The following design-based research approach aims to evaluate the use of cross-age peer tutoring with the goal of providing schools with a concept

that includes training courses and materials, thereby helping schools with a shortage of teachers in STEM subjects. This article provides insight into the development of the project using the design-based research approach. The steps of the design-based research approach will then be looked at in more detail, and the "Minteers" project will be classified within this approach. The article concludes with an outlook and the planned next steps in the project.

Theoretical Foundations

Peer tutoring is an approach that, when looking at the tutors, can contribute to the concept of learning by teaching (Ashlame & Iwanger, 2019). In this concept, students take on responsibilities and can lead parts of the lesson for other students (Martin & Kelchner, 1998).

A definition of peer tutoring, according to Topping (2020, p. 2), divides people into two groups, tutors and tutees, who work in pairs. "Both involve people from similar social groupings [...]" (Topping, 2020, p. 2). Interaction in peer tutoring is defined as "the more able or experienced member helps the other to learn material that is new to the tutor but not to the tutee" (Topping, 2020, p. 2). The definition also refers to the fact that the same experiences and social groups in which the tutors and tutees find themselves contribute to the use of the same language (Topping, 2020, p. 2). Similar language is also mentioned in Cohen's (1986) definition of peer tutoring. This definition also shows an interaction between tutors and tutees in pairs (Cohen, 1986). "The tutor is of the same general academic status as the tutee" (Cohen, 1986, p. 175). However, with regard to cooperation, the definition is further refined (Cohen, 1986). "Peer tutoring is a cooperative dyad composed of members of unequal status, in which the high status member is in a helping role" (Cohen, 1986, p. 180). In Falchikov (2001), the latter aspect is apparent in cross-level tutors, who receive materials and training for tutoring, thereby distinguishing them from their tutees. Nevertheless, she points out that tutors are not teachers, as they have no qualifications (Falchikov, 2001, p. 4). At the same time, same-level tutors are evident when both tutors and tutees have no influence on the materials and thus show similarities to each other (Falchikov, 2001, p. 4f). These similarities are also evident in other definitions (Topping, 1996; Topping, 2020). In Topping (1996, p. 322), tutors are also relieved of the role of teacher and at the same time credited with the opportunity to learn through teaching. "In addition, their interaction may be guided by the provision of structured materials [...]" (Topping, 1996, p. 322), as is also the case in Falchikov's (2001) definition. Topping (1996) describes the work of tutors and tutees in pairs as "less traditional, and more intensive" (p. 322). Rather, the definition refers to a tutoring program with one tutor for several tutees (Topping, 1996), which thus differs from other definitions of peer tutoring in pairs (Cohen, 1986; Topping, 2020). However, the use of multiple group members is also practiced (cf.

Tenhovirta et al., 2022; Tillmann et al., 2021). In Topping (1996, p. 327), the term “cross-year small group tutoring” is used for this.

In the literature, the terms "tutoring" and "mentoring" are often used in a similar context (Kacher, 2007). In order to differentiate between the terms, Kröpke (2014) has attempted to clarify the differences between them. According to Kröpke (2014, p. 27), mentoring involves the sharing of experience from the mentors, for which there is often no training involved. She classifies tutoring as a form of teaching, whereby tutors receive training about teaching methodologies and pedagogical principles (Kröpke, 2014, p. 27). In addition, mentoring focuses on the relationship between mentors and mentees, while peer tutoring focuses on performance (Karcher, 2007). This also leads to an age difference of two or more years in peer mentoring (Karcher, 2007). Karcher (2007) thus defines a cross-age approach as a concept with an age difference of two or more years between the participants. In a study by Topping and Bryce (2004), an age difference of four years was also chosen. In the study by Swanson et al. (2026), as well, the tutors could be one to four years older than the tutees. Both peer tutoring and cross-age tutoring have proven benefits for tutors and tutees (Hidayat & Mohd Saad, 2025). The term cross-age peer tutoring is chosen here to highlight the similar social group through the term "peers" (Topping, 2020) and the age difference through the term "cross-age" (Karcher, 2007). This term has also been used in other studies (cf. Akudo et al., 2025; Korner & Hopf, 2015; Tenhovirta et al., 2022; Topping & Bryce, 2004). At the same time, peer tutoring is defined in this paper based on Cohen (1986), Falchikov (2001), Topping (1996), and Topping (2020) as follows:

In peer tutoring, there are tutors and tutees who work together in groups and work through pre-structured content. Although the tutors have prior knowledge that the tutees do not have. Due to their training, they are not regarded as teachers in the full sense and can communicate as peers.

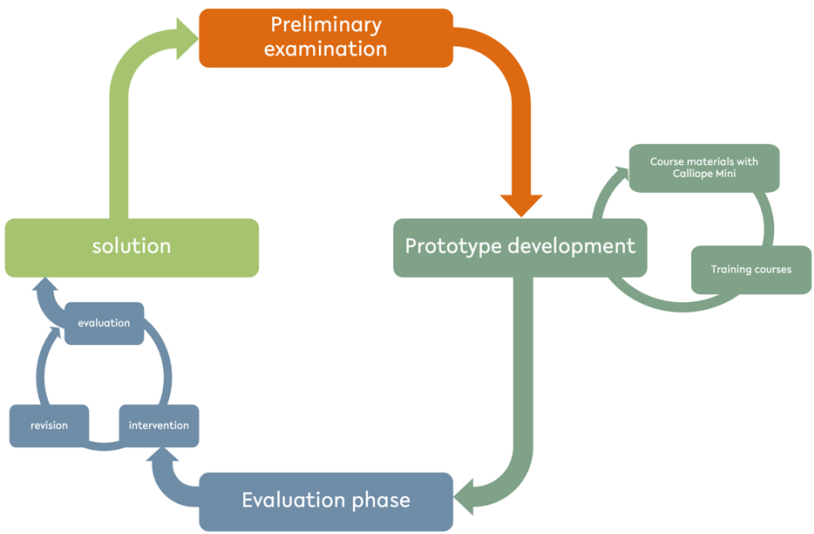
In the sense of Topping (1996), peer tutoring is thus understood as involving more people in the collaboration and allowing one tutor to work with several tutees. Due to the pre-structured content, the tutors are “not regarded as teachers in the full sense,” as stated in Topping (1996) and Falchikov (2001). In order to evaluate the use of peer tutoring in the “Minteers” project and to be able to use it in schools, training courses for tutors and teaching materials were developed, which will be evaluated in the context of the design-based research approach, as they form the base of the AG. In the following, the design-based research approach will be presented, and the concept of the “Minteers” project will be classified within it.

RESEARCH METHOD

To make a connection between theoretical insights and school practice, the design-based Research approach (DBR approach) can provide a foundation for research, such as the project “Minteers“ (Wegner & Schmiedebach, 2023). By involving and mutually interacting with both instances, it is possible to analyze problems as well as explore new theory-based aspects that can be further developed in a subsequent DBR approach (Wegner & Schmiedebach, 2023). An essential component of the approach is "design", which considers the inclusion of practice-based activities in the theory development (Reinmann, 2005). According to Euler (2014), this approach offers the exploration and development of new possibilities for developing strategies for solutions in the educational context. In this iterative process, interventions are reflected upon and adapted in relation to theory and practice (Reinmann, 2005). Hypothesis generation and adaptation enable additional evaluation of the process (Euler, 2014). The cycle of the DBR approach for the "Minteers" project is shown in Figure 1.

Figure 1

DBR approach in the "Minteers" project (based on Wegner & Schmiedebach, 2023)



The first step is the preliminary examination (orange in Figure 1). This begins by considering aspects relevant to practice and is based on theoretical research (Wegner & Schmiedebach, 2023). According to Euler (2014), the first step is to

determine the relevance of the proposed studies, which are both practice- and theory-oriented. This is followed by a literature search to develop interventions and to understand the field of investigation and its possible results (Euler, 2014). In addition, actors involved in the investigations can be included in this process with their experiences (Euler, 2014). Based on the preliminary examination, the next step in the approach is the prototype development, in which initial interventions are developed for the content of the investigations (dark green in Figure 1) (Euler, 2014). In the school context, these include both teaching materials and the development of theory-driven surveys (Wegner & Schmiedebach, 2023).

The next phase of evaluation follows the prototype development and results in the evaluation of the interventions to adapt them (blue in Figure 1) (Euler, 2014). For evaluation purposes, the intervention is implemented in a practical setting (Euler, 2014). This process extends in cycles that provide constant adjustments to the evaluated studies (Wegner & Schmiedebach, 2023). In this context, the iterative process may also need to account for changes that are initiated independently of the results of previous phases, such as personnel changes or constraints, as was the case in Brockmüller et al. (2026). This issue also arose in Langner et al. (2026). "Once the intervention has gained sufficient stability and robustness, it can be subjected to a summative evaluation" (Euler, 2014, p. 33).

Preliminary Examination in the "Minteers" Project

The preliminary examination in the project “Minteers“ was ensured by various aspects. The starting point for the project was the meta-analysis by Chang et al. (2025), which examined the effects of cross-age tutoring. The influencing factors that were the focus of the investigations included, among other things, the type of tutors, the number of sessions, and the teaching content, which was divided between reading and mathematics. Among other methods, moderator analyses were conducted for the study, which concluded that none of the influencing factors predicted a difference in academic performance. In addition to the positive effect of this approach on school performance, Chang et al. (2025) conclude that the use of older students as tutors is beneficial.

Another meta-analysis by Hidayat and Mohd Saad (2025) focused on peer tutoring, specifically in STEM subjects, to examine academic performance and affective aspects. The results showed positive effects on both units of investigation. Among other things, they also conducted subgroup analyses, which showed that the subjects of biology and technology benefit particularly from the tutoring when the focus is on academic performance. This is the case for both peer tutoring and cross-age peer tutoring.

The study by Korner and Hopf (2015) examined cross-age peer tutoring in the STEM subject of physics in Austria. Tutors aged between 12 and 14 taught tutees aged between 8 and 13 in one-to-one sessions lasting 30-45 minutes. Two to three weeks before the tutoring sessions, the tutors received tutoring. In 60 to 80

minutes, they familiarized themselves with the subject matter, prepared for the lessons they had chosen themselves, discussed their own ideas, and worked out misconceptions together. Another 20 to 30 minutes before the tutoring session was used for preparation, for which the tutors were given, among other things, additional cue cards with solutions and questions. To examine the knowledge gain of the groups of people, multiple-choice tests were conducted in a pre-post design with 164 students. The groups of people included tutors, tutees who became tutors after a second mentoring session, and tutees. Among other things, a t-test was conducted, which showed positive effects in terms of knowledge growth, even among tutors in the sample. Further studies by Korner and Hopf (2015) have identified the active role as the reason for the high level of knowledge growth among tutors, even in comparison to pure tutees.

A study by Tenhovirta et al. (2022) also examined cross-age peer tutoring in STEAM subjects, specifically programming and the maker movement. In the study, 15 tutors from an eighth-grade class in Finland worked with 70 tutees from seventh-grade classes. In training sessions, twelve tutors worked in pairs to familiarize the tutees with the GoGo board, which the tutees later used in groups in a maker project. Some tutors were also involved in the maker project. Three tutors took on organizational aspects in the training sessions. The tutors themselves received training on the GoGo Board in advance. The tutor sessions ended with a reflection session, during which additional options for action were developed. Among other things, semi-structured interviews were conducted with the tutors, which revealed that they had encountered challenges. On the one hand, in group supervision, and on the other hand, in implementing the work with the GoGo-Board. In addition, skills that are necessary for tutoring were identified, such as self-regulation skills, technical skills, or pedagogical skills, which, according to Tenhovirta et al. (2022), do not all have to be possessed by one individual, but can be pooled within the group. Their Support for tutees was also considered a positive factor for tutors.

Furthermore, according to the literature, some qualitative interviews were conducted with tutors from the „Satellitenlabore“ as part of the preliminary examination to identify additional implementation hurdles and to incorporate the interview findings into prototype development. In order to find points of contact at school, core curricula in North Rhine-Westphalia were also examined (Ministerium für Schule und Bildung des Landes Nordrhein-Westfalen [MSB NRW], 2019; Ministerium für Schule und Bildung des Landes Nordrhein-Westfalen [MSB NRW], 2021). This served to select school-relevant learning content for the project „Minteers“. Among other things, links to the content area of algorithms for the subject of computer science were selected for the project (MSB NRW, 2021).

Prototype Development in the "Minteers" Project

During prototype development, the teaching material was developed using the Calliope Mini 3 single-board computer, which is particularly well-suited for use in a school setting because it can be used by students as young as elementary school age (Perseke, 2020). In addition, the Calliope Mini supports the promotion of computer science education through physical computing (Romeike, 2017). To take advantage of Hidayat and Mohd Saad's (2025) finding that peer tutoring is particularly beneficial in technical and biological contexts, the teaching material was designed so that students develop a digital turtle, thereby incorporating the maker concept, as in Tenhovirta et al. (2022), and the teaching materials are available in a structured format. In the cross-age peer tutoring in the project, a group of ninth-grade students teaches fifth-grade students. The age was chosen to minimize the need for external support for the tutors, according to Cohen (1986), and thus contribute to reducing the workload of people from the external support. As discussed in the preliminary examination, the positive involvement of older students also favors this choice (Chang et al., 2025). Tutoring in groups was chosen because of the possibility of different, possible, and valuable skills of group members, such as technical or social skills, which can contribute to peer tutoring (Tenhovirta et al., 2022). To address potential challenges, training in the form of training courses for tutors is provided before each course day with tutees. In this, as in Korner and Hopf (2015), from the preliminary examination, the tutors are prepared for the teaching units and potential sources of error are identified, so that technical skills are also acquired. The necessary pedagogical skills mentioned in Tenhovirta et al. (2022) should also be included in the training by addressing aspects of teaching quality and reflecting the previous lessons. A structured lesson plan provides the tutors with additional suggestions for questions, instructions, and possible solutions, as suggested in Korner and Hopf (2015) through the keyword cards. In order to support the recommended six hours of computer science per week in lower secondary school in German High schools, the project consists of 14 course days. This enables the school to offer alternative dates in case of possible cancellations and, at the same time, to integrate training courses between the course days, with two training courses taking place before the first course day. The course days are each 90 minutes long. Half of the course days and training courses take place at the school, while the other half take place at the university. In the future, students in grade 5 may take on the role of tutors in grade 9.

Assessment Phase in the "Minteers" Project

Furthermore, the concept of cross-age peer tutoring will be implemented and evaluated at a school using the materials and training courses. After this step, the prototypes will be adapted and further developed to enable a further phase of evaluation of the project. The following overview of the project provides a look back at the project's goals and outlines the planned next steps.

CONCLUSION

The "Minteers" dissertation project pursues the fundamental goal of the "Satellitenlabore" (Tillmann, 2025). The aim is to evaluate a cross-age peer tutoring project to promote younger students in computer science education. In the future, the project in the AG format should support the recommendations of the Standing Scientific Commission on Education Policy and thus promote and expand the currently provided two hours of computer science per week in lower secondary school in high schools. This is intended to be made possible for schools through the cross-age peer tutoring concept, the evaluated materials, and the evaluated training programs.

In particular, by incorporating the cyclical DBR, the theoretical framework is used to enable the evaluation of the project at additional schools. Implementation hurdles in the use of the concept at schools can also present opportunities to further develop the project in line with the DBR approach and minimize the hurdles. The aim is to refer back to the prototypes to enable further testing of the materials and thus promote the project.

The prototype of the concept will be piloted and evaluated in the 2025/2026 school year at a school in North Rhine-Westphalia. The subsequently adapted concept is to be evaluated at other schools in the 2026/2027 school year.

Tool Statement

The authors used deepl to assist the translation of the text. All ideas, findings, and interpretations are the original work of the authors.

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