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12 Fostering Invention Projects through Cross-Age Peer Tutoring

Sini Davies

Introduction

In this chapter, we introduce cross-age peer tutoring, which refers to a pedagogical approach and infrastructure in which older students with technological expertise systematically support their younger peers in invention projects. Cross-age peer tutoring provides valuable support for teachers, especially in long-standing invention processes and in implementing new digital technologies like microprocessors, robotics, e-textiles, and 3D printing. It allows teachers to concentrate on the pedagogical orchestration of the overall project rather than solving technological challenges. Furthermore, it offers opportunities to use more advanced technologies, as teachers do not have to overwhelm themselves with learning to use or even be familiar with them. On the other hand, cross-age peer tutoring provides ample opportunities for the tutor students for personal growth and have far-reaching positive effects on their futures.

Peer tutoring is not a new approach, although it has been implemented and studied more in tertiary education than at the elementary and secondary levels (e.g., Ching & Kafai, 2008; Fields et al., 2018; Morrison et al., 2010; Topping et al., 2017; Willis et al., 2012). It is a point of emphasis in the newest Finnish curriculum (Finnish National Agency of Education [FNAE], 2016). Peer tutoring pedagogies often focus on transmitting basic skills and promoting positive attitudes to learning rather than engaging tutors and tutees in emergent, knowledge-creating problem-solving and learning novel skills and competencies (Topping et al., 2017). Consequently, many cross-age peer tutoring programs are heavily structured, involve pre-planned learning activities, and aim at pre-specified learning outcomes (Karcher, 2005). In our invention projects, we have focused on developing and investigating cross-age peer tutoring in open-ended, maker-centered learning projects based on nonlinear pedagogy and emergent technology-mediated invention activities (Riikonen et al., 2020a; Tenhovirta et al., 2021).

First, we introduce the theoretical aspects of cross-age peer tutoring from the perspectives of learning and pedagogy. Second, we describe a cross-age peer tutoring model at one of our research–practice partnership lower secondary schools. The school already had an established practice of older students serving as tutors for their younger counterparts. Through invention projects, the school aimed at creating a more systematic approach to cross-age peer tutoring, where eighth-grade

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students from a technology-focused class tutored their seventh-grade peers on the latter students' invention projects. Here, we present two perspectives of the cross-age peer tutoring practices developed during the first year that the invention project was conducted in the school: (1) how tutors experienced cross-age peer tutoring and (2) how peer tutoring in invention projects could be to supported and facilitated. Finally, we discuss the opportunities that cross-age peer tutoring offers for schools, students, and invention pedagogy.

Theoretical Aspects of Cross-Age Peer Tutoring

The theoretical foundation of peer tutoring is often linked to the concept of the zone of proximal development, which Vygotsky (1978) defines as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance, or in collaboration with more capable peers". Later studies emphasize the educational value of peer tutoring as a process of "learning by teaching," where tutors not only provide valuable support for tutees but also learn themselves (e.g., Duran & Topping, 2019). Although peer tutors are not expected to have the pedagogical competences of their teachers, they may still function as "experts by experience" who share their knowledge while challenging themselves to develop new competencies (Mieg, 2006; Olson & Bruner, 1996; Willis et al., 2012).

Maker-centered collaborative invention projects that rely on nonlinear pedagogy and involve open-ended design challenges, novel technologies, and unforeseen and emergent stages and outcomes can be challenging for teachers to orchestrate (Härkki et al., 2021). Neither teachers nor students may be familiar with the technologies that are slated to be used or may emerge during the projects. However, students who have previously conducted such projects or have developed significant digital competencies through informal activities may be much more familiar with these technologies, so engaging such students in invention projects through cross-age peer tutoring can be a valuable asset (Härkki et al., 2021; Riikonen et al., 2020a).

According to Hietajärvi et al. (2020), students with high creative socio-digital competencies developed outside the classroom may lose motivation and become alienated and cynical at school if their skills are not acknowledged. Through cross-age peer tutoring, skilled students can be provided with an acknowledged role, as supporters of their younger peers' design, invention, and making activities (Ching & Kafai, 2008; Duran & Topping, 2019). Karcher (2008) points out that the competence gap between tutor and tutee in peer tutoring should not be too big, ideally no more than two or three years. However, our projects have provided evidence of highly successful digital technology workshops organized by eighth-grade tutor students for elementary and secondary school teachers and even university lecturers and professors. Peer tutoring has the potential to shake up the traditional role of teachers and academics as the only authoritative holders of knowledge in the school community and even more widely in the academic world. Having their skills and contribution socially recognized not only promotes peer tutors' learning and skill development but also potentially strengthens their sense of belonging and self-efficacy (Bandura, 2006; Barron, 2004).

According to Barron et al. (2009), socio-digitally skilled students often have strong informal social networks, both in real life and on the internet. Forming a functional team of peer tutors requires building an active personal social network within and outside team members and even beyond their existing friends to gain access to the knowledge, tools, and competencies they need (Nardi et al., 2000). Furthermore, peer tutoring is a challenging experience that emphasizes the importance of having a supporting social network. Some students may develop a more active and central role within the social network of the tutor team through their "collective cognitive responsibility" (Scardamalia, 2002), through their efforts to advance the team's joint pool of skills, and by forming active and trusted relationships with teachers. In showcases of our own studies (Tenhovirta et al., 2021), we defined these "key tutors" as those with a cognitively central role in providing advice to other tutors and an agentic role within the whole peer tutoring network. Based on our findings, cross-age peer tutoring provides significant support for implementing practices of maker-centered learning and science, technology, engineering, arts, and mathematics (STEAM) education at school (Tenhovirta et al., 2021).

Developing a Cross-Age Peer Tutoring Model at a Finnish Secondary School

A cross-age peer tutoring model was developed to support invention projects in which teams of seventh-grade students participated. The inventor teams were engaged in creating complex artifacts by using digital fabrication and traditional technologies in a learning project integrating science, technology, engineering, and mathematics (STEM) subjects with crafts and visual arts. The school had already used cross-age peer tutoring in other projects but wanted to develop a more systematic approach to it. Meanwhile, having tutor students as part of the teaching team was considered necessary because of the new technologies used in the invention projects, of which the teachers did not have any previous experience.

The invention challenge given to the inventor teams, "[i]nvent a smart product or a smart garment by relying on traditional and digital fabrication technologies or other programmable devices or 3D CAD", was designed jointly by the teachers and researchers. The same invention challenge was assigned to teams in each of three years, so we had three cycles of invention projects. Following our research–practice partnership principle (Coburn & Penuel, 2016; Riikonen et al., 2020a), the projects were designed in close collaboration between the researchers and the teachers against the background of the practical constraints of regular school activity. Two craft and technology education teachers took on primary responsibility for the project; supported by computer science, chemistry, and physics teachers as needed. The projects were conducted during the spring term of 2017 and involved eight to nine weekly design sessions (90–135 minutes per session). The student inventor teams were formed by the students' own choices in the first year, by draw in the second year, and by teachers' choice in the third year, following our experiences and research findings on invention activities in the teams (Riikonen et al., 2020b).

The first group of cross-age peer tutors was introduced to help in the invention projects in fall 2016. At first, the plan for the school's cross-age peer tutoring model was to have an entire eighth-grade class of 15 students as tutors. They were given two hours of training on the GoGo Board programming tool by the Innokas network at the University of Helsinki. GoGo Board is an affordable, multifaceted digital fabrication instrument based on a visual programming language that involves numerous robotic elements like sensors and actuators for external devices (Sipitakiat et al., 2004). It was intended for use in several future invention projects, and the tutors were encouraged to further explore it themselves. Four students voluntarily began spending their free time practicing and experimenting with the GoGo Board and programming. They quickly formed a team of coordinating "expert" tutors. These tutors who showed exceptional agency were asked to co-plan workshops to introduce the GoGo Board to seventh-grade students. In February 2017, training sessions were organized for each of the school's four seventh-grade classrooms. These workshops proved to be highly effective, so in subsequent years, the tutors in each cycle organized similar events for the new inventor teams.

After the training sessions, the craft teacher invited a few tutors at a time to support the seventh-grade students with their invention projects. During those sessions, tutors worked in pairs to help the inventor teams with problem-solving, troubleshooting, and further developing their ideas, with the expert tutors taking responsibility for organizing the peer tutoring activity. From these first sessions onward, the expert tutors took on more and more responsibility for the tutoring; toward the end of the invention projects, they were the only people who helped the invention teams in the classroom. As their expertise in both the technologies and teaching grew, they also started arranging technology workshops for students in other schools and even for teachers from their own and other schools. The teachers highly valued their expertise and input, and the tutors were soon engaged in all levels of technology-related activities in the school community, from tutoring and advisory roles all the way to having input into school-wide technology purchases.

Although functioning in the role of peer tutor was considered motivating and provided positive pro-social experiences of helping others, most tutors desired more structured and better-supported, peer-tutoring processes. To that end, they took an active role in training the next cohort of tutors, selecting six students from the first tutee group to receive deeper computational training, following which they taught new groups of students together. Slowly, during spring 2018, the coordinator team started to step back, giving the new tutors more space to learn and teach when they entered eighth grade. The third cohort of digital tutors took more responsibility for the entire innovation process in 2019: they were more involved in the teams' designing by sharing their expertise in technology, but also by challenging and encouraging the teams to further develop their inventions. Their motivation was high, and they received more training and opportunities to teach or conduct workshops for teachers and students in other schools.

Throughout their time as peer tutors, the first cohort tutors took an active role in developing the tutoring model in collaboration with the teachers and researchers. Based on their experiences and ideas, a tutoring cycle model was developed (see Figure 12.1).

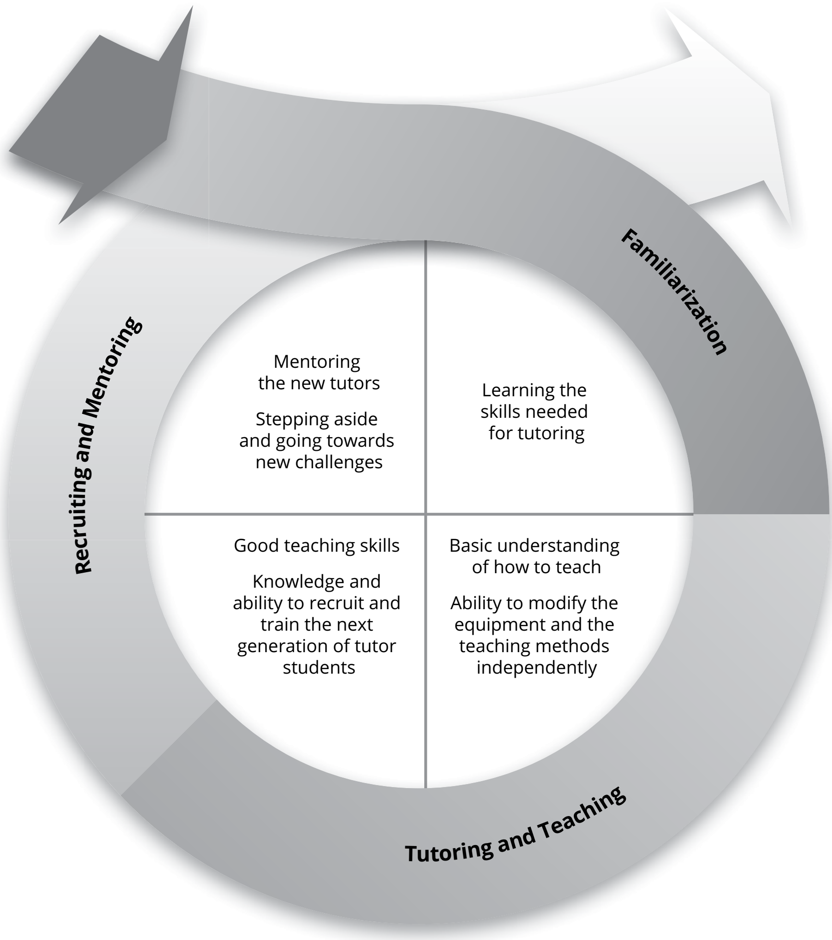

Figure 12.1 Cross-age peer tutoring cycle model.

The cross-age peer tutoring cycle consists of three phases: familiarization, tutoring and teaching, and recruiting and mentoring. During familiarization, the tutors learn and develop basic skills regarding technologies, teaching, and collaborative inventing. In tutoring and teaching, the tutors begin to guide the tutee teams and organizing workshops while they advance their own expertise. Toward the end of this stage, the tutors also begin to expand tutoring outside the classroom, providing their expertise to the whole school community and even outside their school. In the final stage, the tutors recruit a new group of students to become the next year's peer tutors. The advantage of having tutors do the recruiting is that they are part of the school's student community and can more easily find enthusiastic younger students who already are or are keen to become experts in new technologies. Finally, they mentor the new group of tutors, providing them with invaluable support, insight, advice, and information on being a peer tutor.

The effects of this cross-age peer tutoring model on the school's working culture and community extended well beyond the invention projects. The tutor students helped narrow the gap between students and teachers and created a more democratic working culture in the school, especially regarding maker-centered activities. They became an asset to the school's pedagogical team and created mutual respect between teachers and students. As the crafts teacher and school principal put it, the "tutoring model enables students' participation in the school's operation at various levels. It creates a positive, appreciative, heart-to-heart atmosphere in our school".

Tutor Students' Experiences of Becoming and Being Cross-Age Peer Tutors

When developing a long-lasting, cross-age peer tutoring model in a school, the tutor students' experiences of their tutoring journey and its effects on their learning and personal development should not be overlooked. In this section, we present some of the experiences of the expert tutors from the first cohort of peer tutoring; they provide valuable insights into cross-age peer tutoring from their own perspectives. To describe their own cross-age peer tutoring cycle, a time line was created by the author and expert tutor students (Figure 12.2).

According to the findings of our study of the first cohort of tutor students (Tenhovirta et al., 2021), they had to learn and cultivate a multitude of skills to overcome the challenges they encountered as peer tutors. Examples include basic and advanced technical skills, teaching skills like how to explain things to motivate the tutees, social skills (especially regarding collaboration), self-regulatory skills like taking responsibility and exercising self-control, and reflective skills. With only the brief training they received at the beginning of the initiative, they had to actively develop these skills on their own.

Initially, the tutor students felt uncertain of what they should be doing and how to act. They felt that they lacked the skills needed to function successfully as peer tutors; indeed, they did not yet fully perceive what those skills were. They had no

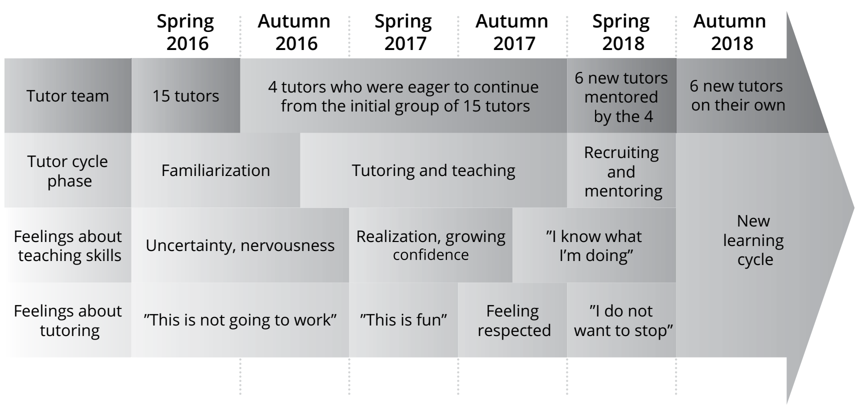

Figure 12.2 The time line of the first cohort of peer tutors.

experience in teaching others and thus felt insecure and nervous. One tutor wrote the following about the early stages: "The start was hard. We weren't sure about what we were doing, and we didn't know what to think about all of it".

The tutor students quickly established collaborative practices that supported the development of their teaching skills. They began to plan and structure the workshops they organized in detail and to systematically reflect on their teaching, especially after the workshops. This process involved making reflective notes and having conversations after the sessions. In the following interview excerpt, one expert tutor describes this approach:

> We wondered how the session should go and what we should show, in what order. And after that, usually after the session, we discussed with Joona [one of the tutor students] how the session went and what I could have done better. There were conversations…of what we had learned in the last session, and it always improved a little.

Gradually, the tutors developed their skills, and uncertainty and nervousness transformed into confidence and joy. The tutor students became a well-organized team, with each having a different role, while working in close collaboration and relying on one another's strengths. Based on our experiences and research findings (Tenhovirta et al., 2021), this team-building process of discovery is very important and may have long-standing benefits for the tutor students' self-confidence. One described this transformation from uncertainty to high confidence and well-organized teamwork as follows:

> We started enjoying what we were doing, finding out new ways of holding the classes, new things to teach, and new challenges…. We had different unspoken roles in the group. I did the talking; then, we had one helping out the students, a coder, and a pessimist who kept our feet on the ground. We all knew what to do, and we felt secure about it. At this point, without our even noticing, this tutor teaching had changed all our suspicions to pure admiration, and we were proud to have the chance to do it. By then, we had developed good teaching methods and equipment and a great attitude toward tutoring.

In both written reflections and interviews, the tutor students described the role of the teachers and the importance of the support they were provided by all parties in the research–practice partnership, emphasizing the independence, responsibility, and respect they were given. They also felt that they became highly respected members of the school's pedagogical team; they also started to respect their teachers even more. This boosted their confidence even further and motivated them to seek to excel in their positions as peer tutors and to develop their skills. One tutor student described the significance of the teachers' role in the following way:

> It is important to mention that during all this time, we weren't on our own. We had the complete support of the crafts and IT teachers, the principal, and the university. In particular, our teachers spent a lot of time with us, but they never tried to act like they were better than we were. Instead, they even

> backed off sometimes and asked our advice. It became a relationship of mutual respect, because we tutors started to appreciate the job they did after trying it out ourselves, and they respected our commitment. I see this as the key. The reason this was possible was our commitment and also our teachers. They supported us by letting us decide on our own. If we had always been guided by one of our teachers, I don't see any way it could have worked.

The first cohort tutor team recruited a new team of tutors from among their younger peers and guided and motivated them to continue their work. The tutors felt that this was an important task and did not want the tutoring model to fade away. This was also an emotional experience for them because they did not want to stop being tutors, but they knew that they had to cede responsibility to a new cohort of tutors and move on with their own studies. Based on our findings (Tenhovirta et al., 2021) and the tutors' writings and interviews, the experience and skills they acquired through their time as peer tutors affected and clarified their future plans and could have far-reaching effects on their futures. This is a very important aspect of peer tutoring from the educational point of view. One tutor crystalized the key effects of peer tutoring on him and his fellow tutors as follows:

> The most important lesson we learned as tutors is to believe. Even if sometimes things do not go as planned or you have a rocky start, it is better to try than to give up. We have also learned to teach and to respect those who teach us. After having the experience of making our own decisions in tutoring, we have learned to take more responsibility, to know our limits, and to have the courage to break those limits.
>
> It has also had a positive effect on our future plans by, for example, clarifying our study paths. For me, it made really clear that I want to follow a path in technological discovery in medicine, and it made me choose to take the scientific and technological class in high school.

Discussion and Conclusions

This chapter focuses on describing the opportunities provided by cross-age peer tutoring for collaborative invention projects, for maker-centered and STEAM learning, and for the tutor students themselves. Over three cohorts of peer tutoring, with the help of the student tutors, we developed a sustained cross-age peer tutoring model for maker-centered learning projects. Our observations and findings indicate that developing a systematic mode of cross-age peer tutoring to support invention and maker-centered learning was a fundamental aspect of the school's pedagogical approach and provided critical scaffolding structures and practices when combined with the teachers' support (Riikonen et al., 2020a; Tenhovirta et al., 2021). The effects of cross-age peer tutoring on the school's pedagogical infrastructure were crystalized through the following four key aspects:

1. Cross-age peer tutoring releases teachers to focus on the overall orchestration of the class and the project, instead of being diverted by technological and practical challenges experienced by individual student teams.

2 More advanced new technologies can be used in maker-centered and STEAM learning when teachers, who already have heavy workloads, do not have to master these technologies.
3 Cross-age peer tutoring promotes a more democratic school community by helping to narrow the gap between students and teachers.
4 For the tutor students, cross-age peer tutoring can offer many opportunities for personal growth and have far-reaching positive effects on their futures.

Authentic invention projects are often nonlinear and engage teams of students in creating unforeseen solutions for ill-defined, authentic, and complex challenges (Viilo et al., 2011). However, these projects can be very challenging for teachers to plan and conduct. Cross-age peer tutoring offers an invaluable asset to support the successful completion of such maker-centered learning projects. With the support of peer tutors, the teacher does not have to concentrate on solving novel and often complex technological challenges, while the tutor students can use their own constantly developing expertise to introduce more sophisticated new technologies into the invention projects. With the help of the tutor students, teachers can take a more comprehensive role in scaffolding the projects and classroom activities. When teachers trust the tutor students and respect their expertise—which often exceeds their own—those students can even be engaged to help plan the procurement of such technologies for the school.

When the school acknowledges the expertise of its students through systematic peer tutoring that can be expanded to many areas beyond technological expertise, it promotes a more equal culture between teachers and students. Based on our observations, even students who do not serve as peer tutors benefit from this building of mutual respect and knowledge exchange. Furthermore, such an open atmosphere of mutual respect could promote the development of a culture of innovation in the school, with the teachers no longer the sole holders of knowledge, and the students no longer passive receivers of it. The educational value of cross-age peer tutoring should not be overlooked in this respect.

Finally, becoming a peer tutor can have long-standing positive effects on students. Cross-age peer tutoring promotes the tutors' self-efficacy and self-image. It also offers them abundant opportunities to learn and cultivate a multitude of skills: technological expertise, teaching know-how, collaboration, taking responsibility, self-control, and reflective skills. Perhaps the most important aspect of self-development among the peer tutor students, based on their own experiences and our observations, has been to believe in themselves and have the courage to take on new challenges. Not being afraid of making mistakes and having the mentality to try again if something goes wrong are some of the more valuable skills to learn in becoming an innovative participant in today's society.

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