Faculty of Educational Sciences
University of Helsinki

UNDERSTANDING THE ROLE OF GAZE IN MOMENTARY TEACHER-STUDENT SCAFFOLDING INTERACTION DURING COLLABORATIVE PROBLEM SOLVING

Eeva Haataja

DOCTORAL DISSERTATION

To be presented for public discussion with the permission of the Faculty of Educational Sciences of the University of Helsinki, in Auditorium 302, Athena Building, on the 28th of January, 2021 at 12 o'clock.

Helsinki 2021

Supervisors

Professor Markku Hannula
University of Helsinki, Finland

Dr., Title of Docent Anu Laine
University of Helsinki, Finland

Pre-examiners

Professor Erno Lehtinen
University of Turku, Finland

Professor Dor Abrahamson
University of California Berkeley, USA

Custos

Professor Markku Hannula
University of Helsinki, Finland

Opponent

Professor Hans Gruber
University of Regensburg, Germany

Cover

Aleksi Vehmassalo

ISBN 978-951-51-6946-4 (pbk.)
ISBN 978-951-51-6947-1 (PDF)

Unigrafia, Helsinki

ABSTRACT

Gaze is a crucial part of nonverbal interaction. In the context of instruction, fruitful nonverbal interaction can enhance student well-being and collaborative learning. Teacher-student relationships are constructed on the basis of momentary classroom interactions. High quality interaction is especially important in the context of collaborative problem solving, where the teachers scaffold the student groups to reach the cognitive, affective, and metacognitive learning goals. Recent eye-tracking research has charted some general patterns of teacher gaze in classrooms, but the momentary dynamics of the relation between teacher gaze and the teachers' pedagogical intentions, and reciprocal teacher-student eye contacts as a part of instructive interaction, have remained unexplored. To address this research gap, the aim of this dissertation was to explore how teachers' momentary scaffolding intentions and interpersonal behaviors are manifested in their gaze behaviors and in momentary teacher-student eye-contact communication.

The research setting included multiple mobile eye tracking in naturalistic classroom contexts. The teachers and four students in each class wore gaze tracking glasses during the data collection lesson. The studies combined three data sources collected on three 9th-grade mathematics lessons: gaze tracking data, classroom video recordings, and a stimulated recall interview with one teacher. The students solved a geometrical problem task collaboratively and the teachers guided the problem-solving process. I started all the analyses by annotating the teachers' gaze data with ELAN software of the teachers, and in Study III the students' gaze data as well. The coding unit in the gaze annotation is a dwell, meaning one gaze at a researcher-specified target from entry to exit. I then coded the teachers' scaffolding intentions (cognitive, affective, and metacognitive) in the synchronized classroom videos. In Study I, the participant teacher's stimulated recall interview complemented the analysis to validate interpretations. For Study III, I chose to use continuous coding of the teachers' interpersonal behaviors. I aimed toward deep exploration of the research topics. This mixed method research combines theoretical and methodological traditions of psychology and education while creating new information on teacher-student interaction, as well as new analytical methods. Thus, using triangulation of statistical analyses (Chi-square, ANOVA, Pearson's correlation) and qualitative descriptions of the interaction events was not only justified, but also necessary.

To summarize the findings of this dissertation, I present two viewpoints. First, the targets of teacher's visual attention can be divided into three categories. Student faces and solution papers (1) were the most significant gaze targets for the teacher. Overall, there were relatively long gaze events on these targets throughout the coded session. Student papers were the most significant target during teacher-led cognitive scaffolding interaction, and

student faces during affective scaffolding. Students' hands and bodies (2), however, were a common gaze target during metacognitive scaffolding as well as during the nonverbal monitoring and fading phases of the scaffolding events. These gazes were numerous but short. On the other hand, teacher gazes at student gestures (3) were few but very long. They occurred often during cognitive scaffolding.

The second viewpoint to the findings is the use of teacher-student eye contact communication. In general, the student-started eye contacts were significantly more frequent than teacher-started eye contacts. The occurrence and durations of the dyadic eye contacts were dependent on the teachers' scaffolding intentions. Dyadic student-started eye contacts were most common (with statistical significance) during cognitive scaffolding. Despite the large amount of teacher attention to students' solution papers, the students tended to look their teachers in the eye during cognitive scaffolding interaction. Instead, during affective scaffolding, the teacher-started eye contacts were relatively frequent. The longest gazes in general occurred in the rarest gaze category, namely teacher-started dyadic eye contacts. The students looked at their teachers during high teacher communion more often and with longer gazes. This was also evident with student-started dyadic eye contacts, when the teacher-student interaction was supporting the achievement of the learning goals of the moment. The student gazes at teacher faces occurred often but were shorter during low teacher agency. However, this result was dependent on the quality of teacher-student interactions, and varied both within and between the classes.

To conclude, during fruitful cognitive scaffolding interaction and teacher behaviors of high communion and agency, the student gazes focus on the teacher and teacher gazes on the learning contents. Additionally, when the teachers offered affective scaffolding by looking at their students with agentic gaze, the students replied to these gaze initiatives, and dyadic eye contacts formed between the teacher and students. The between-individual and even within-individual variation of attentional behaviors underline the relevance of using situational data collection methods and continuous coding. In addition, developing theories on scaffolding intentions and interpersonal behaviors toward the inclusion of the momentary variation in instructive interaction are also important.

TIIVISTELMÄ

Katse on olennainen osa sanatonta vuorovaikutusta. Opetuksen osana laadukas sanaton vuorovaikutus voi edistää oppilaiden hyvinvointia ja yhteistoiminnallista oppimista. Opettajien ja oppilaiden välinen suhde rakentuu tilannekohtaisen luokkahuonevuorovaikutuksen pohjalle. Korkealaatuinen vuorovaikutus on erityisen tärkeää yhteistoiminnallisessa ongelmanratkaisussa, jossa opettajat ohjaavat oppilasryhmiä saavuttamaan kognitiiviset, affektiiviset ja metakognitiiviset oppimistavoitteensa. Viimeaikainen katseenseurantatutkimus on kartoittanut opettajan katseen yleisiä piirteitä. Opettajan katsetta ja katseen tilannekohtaisten pedagogisten tavoitteiden välistä dynamiikkaa tai opettajan ja oppilaan välisiä kaksisuuntaisia katsekontakteja osana opetuksen vuorovaikutusta ei kuitenkaan ole vielä tutkittu. Näin ollen tämän väitöstutkimuksen tavoitteena oli selvittää, miten opettajien tilannekohtaiset ongelmanratkaisun ohjaamisen tavoitteet (scaffolding intentions) ja interpersoonallinen käyttäytyminen (interpersonal behavior) näkyvät heidän katsekäyttäymisessään ja opettajan ja oppilaan välisessä katsevuorovaikutuksessa.

Tutkimusasetelma sisälsi aineistoa useista kannettavista päälle puettavista katseenseurantalaitteista aidoissa luokkahuoneympäristöissä. Aineistonkeruutunneilla nauhoitettiin opettajan ja neljän oppilaan katsetta samanaikaisesti. Katsedatan lisäksi käytin aineistona videonauhoitteita luokkahuoneen toiminnasta ja keskusteluista sekä yhtä oppitunnin jälkeistä opettajahaastattelua. Tuntien aikana oppilaat ratkaisivat geometrista ongelmatehtävää yhteistoiminnallisesti, ja opettajat ohjasivat tätä työskentelyä. Aloitin analyysit annotoimalla opettajien katsedatan ELANohjelmistolla. Osatutkimusta III varten annotoin myös oppilaiden katseita. Analyysiyksikkönä käytin yhtä katsetta tiettyyn katsekohteeseen sen alusta loppuun asti (dwell). Katseiden annotoinnin jälkeen annotoin katseaineiston kanssa synkronoidusta videoaineistosta opettajan ohjauksen tavoitteita luokitellen ne kognitiivisiin, affektiivisiin ja metakognitiivisiin. Tutkimuksessa I oli aineistona lisäksi opettajan oppitunnin jälkeinen stimulated recall –haastattelu. Tutkimuksessa III koodasimme opettajien interpersoonallista käyttäytymistä jatkuvan koodauksen menetelmällä. Tavoitteeni oli ymmärtää tätä suhteellisen tuoretta tutkimusaihetta syvällisesti, ja siksi valitsin monimenetelmäisen lähestymistavan analyysiin. Yhdistin tilastollisia analyysejä (Chin neliö, varianssianalyysi, Pearsonin korrelaatio) ja kvalitatiivista kuvailevaa analyysiä.

Tiivistän väitöstutkimukseni tulokset kahteen näkökulmaan. Ensiksi, opettajan visuaalisen huomion kohteet voidaan jakaa kolmeen kategoriaan. Oppilaiden kasvot ja tehtäväpaperit (1) olivat keskeisimmät katsekohteet opettajalle. Hän katsoi näitä usein ja suhteellisen pitkillä katseilla läpi koko yhteistoiminnallisen ongelmanratkaisun. Oppilaiden tehtäväpaperit olivat

keskeisin katseen kohde kognitiivisen ohjauksen aikana ja oppilaiden kasvot taas affektiivisen ohjauksen aikana. Opettaja katsoi oppilaiden käsiä ja kehoa (2) usein metakognitiivisen ohjauksen aikana, samoin kuin silloin kun ei ohjannut oppilaita puheella vaan tarkkaili heidän toimintaansa. Näitä katseita oli paljon, mutta ne olivat lyhyitä. Sen sijaan opettaja katsoi oppilaiden eleitä (3) harvoin, mutta nämä katseet olivat pitkiä ja tapahtuivat usein kognitiivisen ohjauksen aikana.

Toinen näkökulma tuloksiin on opettajien käyttämä katsekontaktivuorovaikutus. Yleisesti ottaen oppilaat aloittivat kaksisuuntaisen katsekontaktin useammin kuin opettajat. Kaksisuuntaisten katsekontaktien esiintyvyys ja kesto riippuivat opettajan ohjauksen tavoitteista. Oppilaiden aloittamia katsekontakteja esiintyi eniten kognitiivisen ohjauksen aikana. Huolimatta siitä, että opettaja katsoi paljon oppilaiden papereita, oppilaat katsoivat näissä hetkissä usein opettajan kasvoja. Sen sijaan affektiivisen ohjauksen aikana opettajien aloittamat kaksisuuntaiset katsekontaktit olivat suhteellisen yleisiä. Tämä katsekategoria sisälsi vähiten katseita mutta ne olivat pisimpiä. Oppilaat katsoivat opettajiaan kasvoihin useammin ja pidemmillä katseilla, kun nämä välittivät yhteyttä (communion) käyttäytymisellään. Kun oppilaiden aloittamia katsekontakteja esiintyi oppimista tukevan opettaja-oppilasvuorovaikutuksen aikana, ne olivat pitkiä. Sen sijaan oppilaskatseet olivat lyhyitä, vaikkakin yleisiä, kun opettajan toimijuus (agency) oli matala. Tämä tulos kuitenkin riippui vuorovaikutuksen laadusta ja vaihteli opettajien ja luokkien välillä.

Yhteenvetona voidaan todeta, että antoisa kognitiivinen ohjausvuorovaikutus ja opettajan välittämä korkea yhteys ja toimijuus ohjaavat oppilaiden katsetta kohti opettajaa ja opettajan katsetta kohti oppimisen sisältöjä. Lisäksi, affektiivisen ohjauksen aikana, kun opettajat katsoivat oppilaita ohjaavalla katseella, oppilaat vastasivat näihin katsekontaktialoitteisiin, ja kaksisuuntainen katsevuorovaikutus toteutui opettajien ja oppilaiden välillä. Tilannekohtaisten aineistonkeruu- ja jatkuvien analyysimenetelmien käyttäminen tulevaisuuden tutkimuksessa on tärkeää, jotta yksilöiden väliset vaihtelut ja jopa vaihtelu yksilön toiminnan sisällä voidaan huomioida. Interpersoonallisen käyttäytymisen ja ongelmanratkaisun ohjaamisen teorioita on tärkeää kehittää kohti opetusvuorovaikutuksen tilannekohtaisuuden ymmärrystä.

ACKNOWLEDGEMENTS

My supervisors, Dr., Title of Docent Anu Laine and Professor Markku Hannula. With Anu, our journey together dates back to 2010, when I started my bachelor's thesis. Since then, you have always been by my side, whatever I have needed to go on with my academic struggles. You are an extraordinary person, with such ability to give both emotional and academic support. I have learnt so much from you on how to be a researcher, pedagogue, and how to deal with academic life and motherhood.

Markku, first I want to thank you for inviting me to your project and believing in my capability to absorb all the knowledge to conduct proper eye-tracking research. The value of the knowledge I have learned from you goes beyond words. How to write publishable articles, how to operate in a local and international research community, how to organize data collections and conferences, and so on. During the years of working in the MathTrack project, I have gained adequate self-confidence to survive in the academic world on my own, and for that I will always be grateful to you. No matter how tight your schedules are, you have always had time to sit down with me, answer my questions, and, the most importantly, pose new ones. Last but not least, I want to thank you for enabling my trip to Melbourne.

I express my gratitude to my pre-examiners Professor Erno Lehtinen and Professor Dor Abrahamsson for their thorough, insightful and encouraging feedback that helped me in improving this thesis. Your stimulating comments also turned my thinking towards my future as a postdoc researcher. I am extremely thankful for Professor Hans Gruber for accepting the role of opponent at the public defense of my dissertation. I am deeply sorry that we will not be able to meet in person due to the pandemic, but at the same time I am confident that we will meet and ponder on our thinking together in the future. I thank Aleksi Vehmassalo for drawing the amazing illustration for the cover of the dissertation.

For funding my full-time work as a doctoral student, I thank Markku Hannula for hiring me and the Academy of Finland that funded the MathTrack research project (grant 297856). I also express my thanks to the Faculty of Educational Sciences in the University of Helsinki for covering my travelling expenses and for offering me a salaried position for the last six months of writing this dissertation.

My years with this PhD project would have been miserable without our amazing and particular MathTrack team. I have made so many good friends, whom I wish to stay in touch with in the future. Dr. Enrique Garcia Moreno-Esteva, thank you for all the kind and sincere help with methodological ponderings, programming, and language. I have enjoyed collaborating with you and I have learned so much from your expertise. Visku Salonen, thank you for always helping me with the statistics and for saying yes to collaborate on the weird joystick analysis method. I also thank you for funny conversations over (often quite long) lunch breaks. Jessica Salminen-Saari, thank you for sharing the beauty and confusion of simultaneously being a PhD student and a mother of a baby. I have enjoyed studying and collaborating with you. Dr. Miika Toivanen, first of all thank you for developing the eye-tracking equipment

with your colleagues at the Finnish Institute of Occupational Health. I also want to thank you for your support and help with planning, writing and revising the research reports. Dr. Nora McIntyre, thank you for your insightful feedback and eye-opening discussions on my analytical approaches. I hope we will have many changes to work together in the future.

I thank the members of the international research community on mathematics education for sharing your expertise and having fun in the conferences I have participated. The funniest thing about the international conferences is, that you will learn to know and have time to talk with your Finnish colleagues. Among many lovely persons, I wish to mention Juulia Lahdenperä, whose deep understanding on research and academia and empathetic attitude towards life fascinates me.

One of the reasons I enjoyed myself so well at the faculty was the warm-hearted atmosphere in your research community STEAM@Maker. I want to thank all the people within this group for welcoming me into your community and teaching me about the academic work life. Dr. Heidi Krzywacki and Dr. Päivi Portaankorva-Koivisto, I have learned from you more than you know. I hope to meet you many times in the coffee room next to the mathematics class to ponder on interesting topics over coffee. Anniina Koskinen-Salmia, I have enjoyed our collaboration and I hope it will continue in the future.

In 2018, I had an opportunity to spend two unforgettable months in Melbourne, Australia. I was fortunate to visit the ICCR research group at the University of Melbourne. The greatest thanks are dedicated to late Professor David Clarke, whose overwhelming expertise and friendly hospitality taught me more I could have hoped. Carmel Mesiti, thank you for the insightful scientific conversations and for taking care of me emotionally and in practice. I will never forget that lasagna you cooked when you invited us to your beautiful home to meet your lovely family. Dr. Esther Chan, I have learned a lot from your expertise, and I am glad to continue academic work with you. I am grateful that you continue gathering the researchers around the Social Unit project so that we can support and learn from each other.

Dr. Laura Tuohilampi and Dr. Juuso Nieminen, there is something magical in Melbourne. How did we become such good friends in such a short time, and how did that trip change all our lives? Thank you Laura for being my sparring partner at the gym and in the academy, I wish from my heart that we will get numerous chances to collaborate at work and at jogging trails. Juuso, I admire the depth of your theoretical thinking and I enjoy our “wine sessions of ontology” that quite often don’t even include wine but are still amusing! I thank you for all the concrete support in the finishing phase of this dissertation, and I hope that we will soon find time to write something together.

My parents-in-law, Ritva and Heikki, thank you for always encouraging and supporting me on this path. Heikki, a recent PhD yourself, thank for being the only one in the family who actually wanted to discuss writing a doctoral thesis and graduating as a PhD. I want to thank the rest of Jukka’s family for being such a lovely extended family to me. Special thanks go to Pia for always being so enthusiastic about pedagogy and ready for pedagogical discussions.

Anna, my dear, we have been through everything. Thank you for always supporting me and saying the right words when I need them. Your thoroughness, loyalty, and humility always impress me. Thank you for taking me to either jogging or for a dinner, when my brain has needed resetting. I also want to thank my friends Anne and Maija for all the joyful moments of relaxation.

I want to thank all my colleagues, other staff, and students of Rekolanmäki primary school. The years in that awesome community made me a teacher I am today. Thank you Merja, for supporting me in the beginning of this journey. Special thanks go to my close friends Kaisa, Riikka, and Maiju. I would not be the teacher I am today without the endless reflections and huge amount of experiences with you. With you, I have learned how to survive the darkest moments of teacher life and you have been there to share loveliest and funniest moments of it.

Sanna and Anni, my dear colleagues and friends from teacher studies. It is not exaggeration to say that without you this would never had happened. Thank you for sharing our excursion to science campus to study minor in mathematics. Your faith in my studies was exactly what I needed to hear every now and then.

My late father, Pertti, thank you for always pushing me further, encouraging me towards mathematics, raising me to stand on my own feet, and teaching me that where there's a will, there's a way. My sister, Selja, thank you for being such a bright person, with the ability to support and challenge me in the right way. Thank you for being there for me when I have needed, and thank you and your partner Jussi for sharing ideas over good food. My mother, Riitta, en tiedä miten riittävästi kiittäisin sinua. Olet aina uskonut parasta minusta ja antanut minulle eväitä luottaa itseeni ja mennä aina elämässä vähän pidemmälle. Kiitos myös sydämeni pohjasta kaikesta konkreettisesta avusta väitöskirjan viimeisten ja Elielin ensimmäisten vuosien aikana.

My husband Jukka, your eyes captured me a long ago, and since then, we have gone through great adventures, with all the ups and downs. Thank you for choosing me, always supporting me, encouraging me, and standing up for me. Thank you for all the mental and concrete support during this PhD process, thank you for travelling to Australia with me, and thank you for taking care of Eliel during the finishing process of this dissertation. There are no words to express what you mean to me, but I hope you know. You inspire me and make me a better person. Always. Rakastan sinua.

Our amazing little boy Eliel, this dissertation is dedicated to you. Thank you for coming to our life and making it perfect. Thank you for making every moment precious and sharing your world with us. Valoni, pikkulintuni, sylikattini. Rakastan sinua.

And finally, our unborn, but already beloved child. Welcome when you are ready. Rakastan sinua.

CONTENTS

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following publications:

I Haataja, E., Garcia Moreno-Esteva, E., Salonen, V., Laine, A., Toivanen, M., & Hannula, M.S. (2019). Teacher's visual attention when scaffolding collaborative mathematical problem solving. *Teaching and Teacher Education, 86*. https://doi.org/10.1016/j.tate.2019.102877

II Haataja, E., Toivanen, M., Laine, A., & Hannula, M. (2019). Teacher-student eye contact during scaffolding collaborative mathematical problem-solving. *LUMAT: International Journal on Math, Science and Technology Education, 7*(2), 9–26. https://doi.org/10.31129/LUMAT.7.2.350

III Haataja, E., Salonen, V., Laine, A., Toivanen, M., & Hannula, M.S. (2020). The Relation between teacher-student eye contact and teachers' interpersonal behavior during group work: A multiple-person gaze-tracking case study in secondary mathematics education. *Educational Psychology Review*. https://doi.org/10.1007/s10648-020-09538-w

The publications are referred to in the text by their Roman numerals.

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

Traditionally, visual attention researchers have separated the research participant and the stimulus (e.g. pictures on display) from each other and investigated the actions and reactions of the participant in laboratories. However, in the real world of social interaction, each person's behavior influences the direction of the other persons' gazes, and this necessarily has an impact on any research results about people's gaze behavior. Humans create and recreate the interaction in concert with each other and the particles of interaction (e.g. gazes) construct a new, shared understanding among the participants (Goodwin, 2017). For example, the teacher simultaneously attends to and acts in the interaction with students, and by examining these interlocutors distinctly from each other, researchers are in danger of losing significant information related to the reflexive nature of such interaction. In a literature review on professional learning through video recordings, Gaudin and Chaliès (2015) conclude that "in coming years it will be important to study the similarities and differences between identifying and interpreting relevant classroom events on video and performing these same activities in the classroom" (p. 57). Hence, teachers' attention and their instructional practices should be investigated together to reach a comprehensive picture of classroom interactions.

Creating new knowledge by exploring the reciprocal nonverbal interaction between people in real social contexts can provide "fundamental new insights and directions of research" on social attention (Risko, Richardson, Kingstone, 2016). Mottet, McCroskey, and Richmond (2016) suggest that unintentional and indirect nonverbal messages play an even bigger role in instruction than those messages that teachers and students are aware of expressing. There is a reciprocity in the effects of nonverbal messages between the teachers and students (Mottet et al., 2016), as they co-create shared actions that construct the instruction interaction (Goodwin, 2017). Momentary micro-level interactions build macro-level teacher-student relationships (Pennings et al., 2018). For instance, good interaction (e.g. purposeful eye contacts) enhances both learning and well-being in the classroom (Esmonde, 2009; Roseth, Johnson, & Johnson, 2008).

For students' future learning, collaborative mathematical problem solving is a central skill and thus an essential content of instruction and, therefore, an important research topic (Kojo, Laine, & Näveri, 2018; OECD, 2019; Törner, Schoenfeld, & Reiss, 2007). A teacher's role in this type of instruction is crucial for reaching the abstract learning goals of mathematical problem tasks (Pólya, 1957; Rosales, Vicente, Chamoso, Muñeza, & Orrantia, 2012). Teacher activities during a problem-solving process is called scaffolding. In a scaffolding interaction, the teacher intends to provide sufficient cognitive, affective, and metacognitive support to students according to their needs (Van

de Pol, Volman, & Beishuizen, 2010). A teacher's pedagogical intentions become manifest in their behaviors during interaction, where they can convey momentary agency and friendliness to the students (e.g. Kiesler, 1983). of Good quality scaffolding interaction enhances student learning and benefits teacher professional development (Rojas-Drummond & Mercer, 2003).

Teacher expertise takes shape in teachers' visual attention: through professional development, teachers learn how to pay attention to visual targets that are essential for the instruction (Cortina, Miller, McKenzie, & Epstein, 2015; Dessus, Cosnefroy & Luengo, 2016; McIntyre et al., 2019). However, how do we know what is essential for the instruction? In their review article, Beach and Connel (2019) suggest that "employing eye tracking methodology to track moment-to-moment processes that occur during learning can generate comprehensive data about teachers' behavioral patterns and decision-making strategies." In other words, by harnessing the current eye tracking technology for educational research, we can explore the implementations of teachers' situational pedagogical knowledge from a completely new perspective.

Pedagogical situations form an extremely complex interactional and perceptual context to work in. Teachers' gaze is guided by both their intrinsic intentions and extrinsic stimuli affecting each other (Prieto, Sharma, Kidzinski & Dillenbourg, 2017; Veneri, Rosini, Federighi, Federico & Rufa, 2012). Gaze behavior and visual perceptions are partly unconscious (Galley, Betz, & Biniossek, 2015; Tatler, Kirtley, Macdonald, Mitchell, & Savage, 2014), and to explore gaze we need to capture it with eye tracking in natural situations (Shayan, Bakker, Abrahamson, Duijzer & van der Schaaf, 2017). Together with verbal data, these perceptions offer a unique insight into micro-level processes in the teacher's cognitive processes and teaching situations (Magnussen, Zachariassen, Kharlamov & Larsen, 2017; Prieto et al., 2017; Shayan et al., 2017; see also Tatler et al., 2014). Some general characteristics of teacher attention have been charted by recent research (e.g. McIntyre et al., 2019; Wolff, Jarodzka, & Boshuizen, 2017), but the continuous changes and especially the reciprocal eye contact communication in teacher-student interaction have remained unexplored. Due to the unique nature of the instructional context and the needs of new educational knowledge, conducting eye tracking in authentic educational environments through educational theories and measures is crucial for producing valid information (Jarodzka, Holmqvist, & Gruber, 2017).

Recent educational eye-tracking research has found certain general patterns that characterize teachers' gaze behaviors. Nevertheless, this dissertation argues that cross-situational and interpersonal variation is a significant factor in the teacher's visual attention and eye contact communication, because the teacher's personal states, pedagogical continuous changes, and interpersonal communications with students together affect the nonverbal gaze interaction. This momentary nature of teacher gaze behavior has its implications for the methodology and for our understanding of teacher

activities and teacher-student interaction in classrooms. With continuous data from classroom interactions, we can reach out to the processes that affect the interactions and vice versa.

This dissertation summarizes three mixed method case studies on the role of gaze behavior in teacher-student interaction during Finnish ninth-grade mathematical problem-solving lessons. The data included mobile gaze recordings from three teachers and eleven students and stationary classroom video recordings from three lessons. Study I compared teacher visual attention to situational scaffolding intentions. Study II examined the relation between teacher scaffolding intentions and teacher-student eye contacts. The comparison in Study III was between teacher interpersonal behaviors and teacher-student eye contacts. Theories on scaffolding intentions and interpersonal behaviors as well as the key concepts of the eye-tracking research method will be presented in chapter 2, which follows. After that, chapter 3 provides a short review of recent literature on the use of mobile gaze tracking in educational research, on findings about teacher attention, on the role of eye contact in interaction, and on momentary teacher-student interaction.

2 THEORETICAL FRAMEWORK

In problem solving, the teacher's role is to support the learning process of the students (Wood, Bruner, & Ross, 1976). The teacher's support, scaffolding, is essential for successful learning in collaborative problem solving (Alfieri, Brooks, Aldrich & Tenenbaum, 2011; Fyfe, Rittle-Johnson & DeCaro, 2012) regardless of the age or background of the students or the discipline of the instruction (Belland, 2017). Scaffolding, which was originally a theoretical concept, has become popular and widespread not merely in research, but also in the practice of education (Bakker, Smit, & Wegerif, 2015).

To scaffold problem solving, the teacher chooses how to interact with the students. Vygotsky's Soviet sociocultural school, in which the scaffolding metaphor was first developed, also acknowledged that interpersonal relationships between teachers and students affect teaching and learning (Forman, Minick, & Stone, 1996). These relationships can be observed through the lens of Interpersonal Theory (Leary, 1957). Interpersonal Theory conceptualizes human interaction behaviors as an interplay of two metaconcepts: Agency and Communion (Gurtman, 2009; Kiesler, 1983). This perspective sees interactional acts as a cycle of initiatives and responses between people (Kiesler, 1983). The cycle tends to obey the principle of complementarity, which creates the experience of functional interaction (Kiesler, 1983). The following sections, 2.1 and 2.2, present the theories on scaffolding and interpersonal behaviors that served as theoretical frameworks of data analyses in this dissertation. In section 2.3, I introduce some central concepts of human visual attention and eye-tracking research.

2.1 SCAFFOLDING INTERACTION IN PROBLEM SOLVING

Scaffolding is teacher-student interaction with certain structures and intentions (van de Pol, Volman, & Beishuizen, 2012).The term "scaffolding" is based on a metaphor for construction work and refers to the teacher's actions of controlling the elements of the problem task that are beyond the learner's capacities and abilities (Wood et al., 1976). Ausubel (1963) first mentioned the metaphor in literature. However, it can be found in Vygotsky's personal notebook from 1929 (Shvarts & Bakker, 2019).

The metaphor has generally been seen to be in close relation to Vygotsky's (1978) theory on the Zone of Proximal Development, even though Wood et al. (1976) did not explicate this connection (Bakker, 2014). By the Zone of Proximal Development, Vygotsky (1978) refers to the mental zone between a learner's actual and potential capabilities. Vygotsky (1978) states that "what children can do with the assistance of others might be in some sense even more

indicative of their mental development than what they can do alone" (p. 85). With the assistance of teacher's scaffolding, the learner can achieve the goals of the Zone of Proximal Development that would otherwise remain too demanding (Bakker et al., 2015).

Scaffolding can happen in different modalities. By reviewing literature on scaffolding, Belland (2014) divided modalities into three categories: one-to-one teacher-student scaffolding, peer scaffolding, and computer-based scaffolding. Of these, one-to-one scaffolding can be considered the ideal modality, where the teacher supports the student with tailored instruction to reach the goals of the Zone of Proximal Development (Belland, 2014). Teacher-student scaffolding interaction also occurs at a social level during peer collaboration. Teacher-student scaffolding in collaborative contexts enhances the learning of individual students as well as the professional development of the teacher (Rojas-Drummond & Mercer, 2003).

Wood, Bruner, and Ross (1976) have defined six functions of the scaffolding process. First, the teacher *recruits* the students into solving the task. *Reduction in degrees of freedom* refers to simplifying the task by reducing the number of alternative solution options. By *direction maintenance*, Wood et al. (1976) refer to the teacher's actions in attempting to keep the learner's attention on the task and directing the process toward the goal. Meanwhile, the teacher *marks features that are critical* for finding the successful solution. The teacher should also practice *frustration control* to guarantee the learner's engagement without needlessly restricting the learner's independency. Finally, *demonstration* refers to modeling or idealization of the optimal solution when the learners are approaching it (Wood et al., 1976).

Van de Pol, Volman, and Beishuizen (2010), continued this work in their literature review and defined scaffolding as a contingent interactive process between the teacher and students, where the teacher observes students' needs for support and finally transfers the responsibility of the learning process to the students by fading out the amount and intensity of scaffolding as students' actions and competence allow. Fading can be seen as a result of effective scaffolding (Bakker et al., 2015). Some studies criticize the use of the term fading, and they suggest that the transfer of responsibility can happen even if the teacher retains the control over the learning process (Belland, 2014). However, this dissertation uses the concept of fading on account of the methodological approach. In the gaze data, the scaffolding interaction included short phases where the teachers withdrew from the verbal interaction and removed themselves from the student group.

Because problem solving as a learning method requires various skills from the students, teachers also need to know what kind of scaffolding the students situationally need for success. In scaffolding, teachers make pedagogical decisions on the amount and contents of interventions with the student group. Teachers base their situational scaffolding decisions on their observations of the student groups and their interaction. To provide sufficient but not

exaggerated support, the teacher has to analyze carefully how students construct and try to carry out the task (Hermkes, Mach, & Minnameier, 2018). When making decisions on the contents of the required scaffolding, teachers implement pedagogical intentions. Van de Pol et al. (2010) have reviewed the use of Wood et al.'s (1967) scaffolding functions in the literature on scaffolding interaction and have categorized teachers' scaffolding functions into three scaffolding intentions: cognitive, affective, and metacognitive.

Cognitive scaffolding refers to the teachers' actions in restructuring or adapting the problem task to correspond with students' competences (van de Pol et al., 2010) by means of representing, planning, executing, and self-regulating (Mayer & Wittrock, 2006). Teachers can support students' cognitive processes by explaining the contents of the task, asking questions, and giving clues (van de Pol et al. 2010) without restricting or funneling the learning process (Anghileri, 2006). Students need cognitive scaffolding during all phases of a mathematical problem-solving process (Ding, Li, Piccolo, & Kulm 2007) to reach the objectives of mathematically elegant, reflected solutions through target-oriented student interaction and collaboration (Mayer, 2004).

Affective scaffolding refers to teachers' activities that are intended to prevent students' frustration and increase their motivation (van de Pol et al., 2010). High-quality peer interaction (Barron, 2003) and positive emotions (Pekrun, Lichtenfeld, Marsh, Murayama, & Goetz, 2017) enhance the implementation of academic skills. This also seems evident in the context of instructional scaffolding, as motivational scaffolding has been found to support the cognitive outcomes of the learning process (Belland, 2017). The group members' positive interdependence enhances beneficial peer interaction in problem-solving situations. The teacher can promote positive interdependence by rewarding group achievements, emphasizing peer support, and creating an encouraging learning environment (O'Donnel, 2006). Additionally, social well-being and collaborative goal structures that improve learning outcomes can be reached only through supporting high-quality peer interaction and the joint attention of the students (Esmonde, 2009; Roseth et al. 2008).

Metacognitive scaffolding refers to helping students to direct their attention and interaction towards the learning process (van de Pol et al., 2010). Students' sufficient prior knowledge of metacognitive processes are essential preconditions of a successful problem-solving process (Mayer & Wittrock, 2006). In collaborative problem solving, metacognitive intentions of scaffolding aim to activate students' metacognition on both the intra- and interpersonal levels to enhance the quality and quantity of learning (Molenaar, van Boxtel, & Sleegers, 2010). The important metacognitive skills are the students' ability to maintain joint attention, elaborate their own thinking, and respond to other students' suggestions (Barron, 2003; Ding et al., 2007; Esmonde, 2009). Especially with demanding problem tasks, the successful

learning process requires metacognitive negotiation in the collaboration group (Iiskala, Vauras, Lehtinen, & Salonen, 2011).

2.2 TEACHER INTERPERSONAL BEHAVIOR

Leary (1957) defined all behaviors that relate overtly or covertly to one or more other people as interpersonal. Interpersonal Theory (Leary, 1957) conceptualizes human interaction through a two-dimensional representation of initiatives and responses between people. These dimensions form a Cartesian coordinate system, axis y referring to acts of *Agency* and axis x to acts of *Communion* (Gurtman, 2009; Kiesler, 1983). Agency refers to actions of control, power, and status that convey a person's urge to be differentiated as an individual, while communion connotes love, union, and affiliation that manifest a person's strive for belonging in a social entity (Gurtman, 2009; Wiggins, 1991). Responses to the acts of another person include both covert and overt aspects, and are influenced by the respondent's personal traits (Kiesler, 1983). In the long term, the tendencies in these behaviors create a person's (a teacher's) interpersonal style (Wubbels, 1993). The theory was originally developed from the psychiatric perspective for human interaction in natural and unintentional contexts (Leary, 1957), but is also widely used in professional and institutional contexts, such as therapy (e.g. Kiesler, 1983) and education (e.g. Brekelmans, Wubbels, & Créton, 1990).

In the literature, acts of agency and communion have been studied from several perspectives and under various disciplines. In the literature in the field of psychology, the behaviors of agency (e.g. Wiggins, 1991) are seen to be relative to the concepts of control (Kiesler, 1983), autonomy (Erikson, 1964), social authority (Mehrabian, 1972), dominance (Akechi et al., 2013), and power (Leary, 1957). The perspectives of power (Brey & Shutts, 2015) and social status (McIntyre, 2016) are also important in educational research. Brey and Shutts (2015) suggest that attending school teaches children to observe the presence of power relations in social interaction, because the school community naturally includes clear and salient power structures. In this dissertation, I use the concept of agency to describe a person's behaviors that vary from dominance to submission. It is also important to point out that this dissertation does not examine power structures in schools or teacher or student agency as a trait.

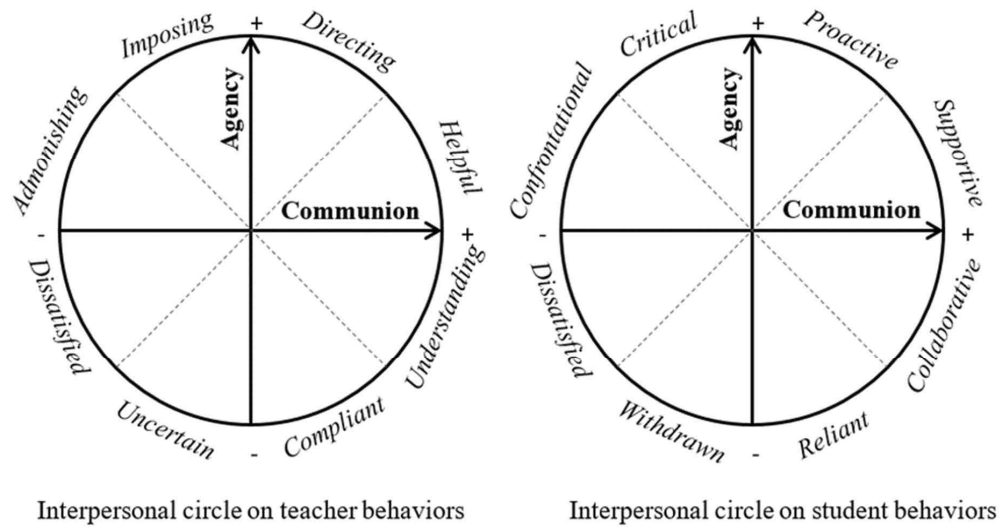

Figure 1 The cycles for teacher and student interpersonal behaviors (adapted from Pennings et al., 2018; see also Claessens et al., 2017). The student interpersonal cycle refers to the student's interaction with the teacher.

On the axis x in the interpersonal circle, there is communion (Wubbels et al., 2012), also called affiliation (Kiesler, 1983; Leary, 1957), cooperation (Brekelmans et al., 1990), trust (Erikson, 1964) and proximity (Wubbels, 1993). As a concept, communion is close to nonverbal immediacy (Andersen, Andersen, & Jensen, 1979). Both can be seen as behaviors that create interpersonal closeness, and both traditions acknowledge the role of eye contact in creating a positive attitude, agreement, and conveying affiliation in human interaction (Andersen et al., 1979; McIntyre, 2016). However, the concept of immediacy includes the idea of internal liking that is reflected in immediacy behaviors (Guerrero, 2017), whereas interpersonal communion refers to external behaviors that are to a large extent responses to the interpersonal cues of other people (Kiesler, 1983). We know that teachers' expressed emotions are not necessarily the same as they sincerely feel (Praetorius, McIntyre, Klassen, 2017), and these faked emotions can even enhance the quality of teacher instruction behavior (Burić & Frenzel, 2020). Thus, I decided to focus on analyzing teachers' explicit behaviors and to use concepts from Interpersonal Theory, namely agency and communion.

These acts tend to comply with the principle of interpersonal reciprocity (Leary, 1957), and they form a continuous cycle of complementary interpersonal behaviors. The behaviors of agency evoke a response of reciprocity, whereas the behaviors of communion evoke a response of correspondence. In other words, high agency is responded to with low agency, and high communion with high communion, and vice versa (Gurtman, 2009;

Kiesler, 1983). In addition, the intensity of a person's reactions are complementary. Intense acts evoke intense responses, whereas mild acts evoke mild responses (Kiesler, 1983). However, a person (a teacher) can direct the other person's (a student's) interpersonal behavior towards the preferred direction by acting with anticomplementarity (Kiesler, 1983). Complementarity in human interaction is in relation to participants' feelings of interpersonal synchrony (Sadler, Ethier, Gunn, Duong, & Woody, 2009).

One important aspect in examining and interpreting interpersonal behaviors is the observation that people have the ability to anticipate and predict each other's behaviors (Pennings, et al., 2018; Sadler et al., 2009), and thus interpersonal behaviors are not to be seen simply as a stimulus-response process (Sadler et al., 2009). This anticipation is present in the teacher's visual attention in scaffolding interaction (Shvarts & Abrahamson, 2019). People tend to adapt their behavior based on not just the actual but also on the anticipated behaviors of others. This may be especially evident in the complex contexts of socially unequal partners, such as parents and children (Sadler et al., 2009) or teachers and students (Pennings et al., 2018). This makes interpreting the results of interpersonal examinations challenging.

Agency and communion have implications in a classroom context. A strong sense of agency has been found to enhance a teacher's professional learning and ethical sustainability (Molla & Nolan, 2020), whereas experiences of inadequacy in teacher-student interaction correlate with a sense of low professional agency among novice teachers (Heikonen, Pietarinen, Pyhältö, Toom, & Soini, 2017). High teacher communion, together with a right amount of teacher agency improves students' affective outcomes (Brekelmans et al., 1990). Teachers' behaviors of communion may also improve students' ability to accommodate (Pennings, et al., 2018).

2.3 MAIN CONCEPTS OF EYE-TRACKING RESEARCH

The human visual field consists of central and peripheral areas. Peripheral vision covers over 99% of the visual field. Even though this area cannot perceive acutely, it helps us in creating a coherent picture of the surroundings and in reacting to the motions of other objects in the environment (Holmqvist & Andersson, 2017). The central area is the very narrow field (< 2°) in the middle of the visual field, where humans can see sharply enough to, for example, read text (Holmqvist & Andersson, 2017; Land, 2006) and perceive colors (Henderson, 2011). The perceptions of the central vision are created in the fovea, a small area at the back of the eye, where the cone cells are packed densely for acute interpretation (Holmqvist & Andersson, 2017). If we want to perceive the details of our environment, we have to aim our central vision to the right object (Hollingworth, Schrock, & Henderson, 2001). The direction of the central area constitutes the human visual attention (Buswell, 1935;

Holmqvist & Andersson, 2017) to the target, which contains the relevant situational information for our task performance (Land, 2006).

The human brain does not decode the visual perceptions as a continuous video stream but as consecutive snapshots as the eye movements stabilize on targets (Lappi, 2016). In gaze tracking research, the concept of fixation refers to the stabilization of the visual attention at a target between saccades (Lappi, 2016). The human gaze consists of approximately three to four fixations a second with saccades between them (Henderson, 2011; Tatler et al., 2014). The durations of the fixations vary vastly due to the within-individual changes, such as the intention of the gaze (e.g. scanning or memorizing), and external factors, such as the light conditions and the obscurity of the target (Henderson, 2011; Holmqvist & Andersson, 2017). Saccades are very fast movements between fixations during which we do not collect visual information (Holmqvist & Andersson, 2017).

In research, the researcher has to define the gaze targets and their boundaries from the whole environment in which the participants' gaze moves. These gaze targets are often called areas of interest (e.g. Holmqvist & Andersson, 2017). The sequence of the gaze targets define the gaze behavior of the participant (Lappi, 2016). Those consecutive fixations that focus on the same target constitute one dwell (Holmqvist & Andersson, 2017).

In 1980, Just and Carpenter created a fundamental theory for eye tracking, namely *the eye-mind assumption*. According to the eye-mind assumption, "readers interpret a word while they are fixating it, and they continue to fixate it until they have processed it as far as they can" (Just & Carpenter, 1980, p. 350). Most of the eye-tracking research relies on this assumption substituting images for words. (Holmqvist & Andersson, 2017; Lappi, 2016). However, eye tracking is not mind reading, and situational qualitative descriptions are often needed to understand the statistical findings (Hannula, Toivanen, Garcia Moreno-Esteva, 2019; cf. Hartmann & Fischer, 2016). For example, paying attention to a certain target more than the others targets that surround it may reflect either its meaningfulness and fascination or its vagueness and unclarity (Hyrskykari, Ovaska, Majaranta, Räihä, & Lehtinen, 2008). Certain tasks tend to yield similar attentional patterns if the data collection is repeated (Lappi, 2016). The timeliness of the fixation direction in the environment also sets requirements for methodology: as the visual processing is so situational and goal-oriented by nature, stable photos or even videos may not provide sufficient stimuli for scientific interpretations (Tatler, Hayhoe, Land, Ballard, 2011).

Additionally, visual attention is not purely directed by the characteristics of the momentary stimuli, but also by numerous cognitive variables, such as a person's memory and intentions (Henderson, 2011). In everyday tasks (Land, 2006) as well as during teaching (McIntryre & Foulsham, 2018), visual attention is mainly directed by *top-down processes*. This means that a person's previous knowledge, intentions, and memories direct the fixations toward task-relevant targets, and the person ignores other targets in the

environment (Land, 2006). Top-down attention also directs the gaze sequences on the task-related targets. Our previous experiences tell us what to look at and do and in which order to accomplish the task (Tatler et al., 2011). When the gaze behavior consists purely of reactions to external stimuli, it is called *bottom-up processing* (Land, 2006).

Collecting data in natural ecological environments rather than in laboratories is a relatively new approach in eye tracking (Lappi, 2016), but is essential for the validity of the research (Hessels, 2020; Kredel, Vater, Klostermann, Hossner, 2017). An even more novel method is multiuser eye tracking, i.e. simultaneously tracing the gaze behaviors of more than one participant. Some recent studies have been published on the collaborative use of a shared system interface by dyads of participants (Tchanou et al., 2020), for example, a tutor and a learner solving a mathematical task (Shvarts & Abrahamson, 2019), and using gaze cues for collaborative search (Zhang et al., 2016). Rogers, Speelman, Guidetti, and Longmuir (2018) found same general gaze patterns, such as the distribution of gazes on the eyes and the mouth, evident in dyads of real people and when looking at photos or videos of human faces. Nyström, Niehorster, Cornelissen, and Garde (2017) have developed methods for online sharing of numerous screen-based gaze recordings. Our research project adds the naturalistic context to the method of multiple mobile gaze tracking.

3 LITERATURE REVIEW

Research on teacher awareness with video stimuli indicates that teachers' attention and awareness are intertwined with their instructional intentions, and scaffolding skills can develop by improving teacher awareness in the classroom (Smit & van Eerde, 2011). Most of the studies on teacher attention still use screen-based eye tracking (e.g. van den Bogert, van Bruggen, Kostons, & Jochems, 2014) or compare the empirical findings on visual attention to the teacher's static characteristics, such as expertise (e.g. McIntyre, 2016). Only a few studies investigate the teacher's gaze in relation to authentic, situational classroom events (e.g. Pouta, Lehtinen, & Palonen, 2020; Prieto et al., 2017).

This section examines the state of eye-tracking research in the context of education. I start by presenting the development of gaze tracking as a method of data collection in the educational research context (3.1). The methodology has developed from laboratory settings and screen-based gaze trackers toward multiple mobile gaze tracking in naturalistic environments. Secondly, I present the recent findings of this approach, mainly from the perspective of teacher attention (3.2). Despite the increasing interest and expanding findings on the role of gaze behavior in classroom interaction, very few studies exist on student perspective or on reciprocal eye-contact interaction between teachers and students. Third, I present some recent research on the role of eye contact in human interaction (3.3). This subsection includes research from both educational and psychological backgrounds, as the body of educational gaze-tracking research is in a developmental stage. Finally, I present findings on the momentary adaptation of teacher-student interaction (3.4) to provide a picture of the contemporary use of Interpersonal Theory in educational research. I end this chapter with a summary of the theoretical perspective this dissertation adopted (3.5).

3.1 MOBILE GAZE TRACKING IN EDUCATIONAL RESEARCH

The interest in examining gaze behavior in educational contexts has increased vastly in the 2010s, especially after 2014 (Strohmaier, MacKay, Obersteiner, & Reiss, 2020). According to a recent literature review, almost 90% of eye-tracking research in education uses static, screen-based eye-tracking technology that records the participant's eye movements when looking at a computer screen (Strohmaier et al., 2020). These reports cover research on the visual literacy of teacher students (e.g. Jian, & Wu, 2015; Kabugo, Birevu Muyinda, Masaazi Masagazi, Muwagga Mugagga, & Bwanika Mulumba, 2016; Lévesque, Ng-A-Fook, & Corrigan, 2014), expert and novice teachers' cognitive processes during an online task (Dogusoy-Taylan, & Cagiltay 2014), and

students' attention when solving mathematical tasks on mobile devices (Shayan et al., 2017). "Teacher noticing" has been a significant approach to investigate the teaching profession with screen-based eye tracking (e.g. van den Bogert et al., 2014; Wolff, Jarodzka, van den Bogert, & Boshuizen, 2016; Wolff, Jarodzka & Boshuizen, 2017; Yamamoto, & Imai-Matsumura, 2013).

In addition to screen-based eye tracking, several reports have been published that use mobile gaze tracking. Here I introduce studies in which teachers are participants. With mobile gaze tracking glasses, the research can reach a deep understanding of teachers' momentary actions and social interaction in authentic classroom context (Beach & McConnel, 2019). McIntyre collected a large data set with 40 teachers from Hong Kong and the United Kingdom by recording the gaze behavior of the teachers in the teacher-centered instruction phases at the beginning of lessons. Reports published on that data reflect the differences in teacher attention between groups of different cultural backgrounds and degrees of expertise (e.g. McIntyre, & Foulsham, 2018). The comparison of pedagogical attention between experts and novices has been of interest in other research groups as well, for instance from the perspective of gaze distribution between students (Cortina et al., 2015) and the mathematical contents of fraction tasks (Pouta et al., 2020).

Another approach to mobile gaze tracking, which is the closest to ours, compares teachers' gaze behavior in different pedagogical situations. Prieto et al. (2017) analyzed teachers' cognitive load in the changing classroom situations on mobile gaze recordings, and Stürmer, Seidel, Müller, Häusler, and Cortina (2017) compared preservice teachers' visual attention between simulated teaching situations and real classrooms.

Some research reports with mobile gaze tracking in an educational context have been mainly methodological. Praetorius et al. (2017) have reflected on teachers' reactivity to gaze tracking equipment and conclude that teachers forget about the research setting after a short period of time and then no longer pay attention to research equipment in the classroom. Data collected among families visiting an educational science exhibition revealed that wearing mobile eye trackers did not bother the adult participants' experience but was sometimes disturbing to their children (Magnussen et al., 2017). Garcia Moreno-Esteva, Kervinen, Hannula, and Uitto (2020) have developed an analytical method to analyze visual scanning behavior.

Where scaffolding interaction is reciprocal, so is the gaze behavior in social contexts (Risko et al., 2016). Nevertheless, very few educational studies have been conducted with multiple gaze tracking. Shvarts and Abrahamson (2019) used dual mobile eye tracking on pairs of university students to track the visual processes in tutor-student interaction while solving a geometry task.

3.2 TEACHERS' ATTENTIONAL PROCESSES IN THE CLASSROOM

The most important sources of visual information for the teacher are the students and the teaching equipment (learning materials, blackboard, etc.) (McIntyre et al., 2017; Praetorius et al., 2017). Expert teachers have been found to prioritize paying attention to students during teacher-centered instruction, whereas novice teachers paid more attention than the experts to non-instructional targets, such as walls and windows (McIntyre, Jarodzka, & Klassen, 2019). Teachers' visual attention is mainly directed by top-down processes rather than bottom-up perceptions on salient external stimuli (McIntryre & Foulsham, 2018). This means that teachers' previous knowledge and pedagogical vision directs their gaze behaviors, and teacher expertise can be seen in their gaze sequence (McIntryre & Foulsham, 2018). From this perspective, it is interesting that research findings contradict the interpersonal variation of gaze behaviors of novice and expert teachers. Stürmer et al. (2017) found large variation in the gaze behaviors of preservice teachers, whereas van den Bogert et al. (2014) found expert teachers' gaze behavior varies more than that of novices. Stürmer's et al. (2017) research was conducted with mobile eye tracking in authentic classrooms, whereas van den Bogert et al. (2014) collected their data with static eye tracking while watching classroom videos.

At the level of gaze fixations, the differences emerge in the proportion, duration, and frequency between the gaze targets. McIntyre, Jarodzka, and Klassen (2019) have developed the use of the measure of gaze proportion in the field of educational research. Gaze proportion refers to the relative amount of visual attention paid to certain targets. According to McIntyre et al. (2019), teachers' gaze proportions during instructional interaction reflect their pedagogical decision-making priorities that are relative to their teaching experience and cultural backgrounds. For example, teachers tend to attend more frequently to those students who are not concentrating in the instruction, which leads to a high proportion of the attention given to them (Yamamoto & Imai-Matsumura, 2013). Expert teachers direct long fixations to those students they are guiding and are flexible in changing the area of interest as a response to students' cues (McIntyre et al., 2017). Nevertheless, short fixations can result from either the advanced skills of sharing attention between multiple students and interpreting classroom events, or not noticing the students' cues (van der Bogert et al., 2014).

As the teachers focus on managing the class to enhance the quantity and quality of students' learning (Wolff et al., 2017), they monitor and interpret their actions, make multiple pedagogical decisions, and adapt the lesson plan accordingly (Prieto et al., 2017; Yamamoto & Imai-Matsumura, 2013). This complexity makes continuous perception of relevant visual information essential in teacher expertise (Chi, 2006). Both experience and pedagogical views and values affect the share of the relative amounts of teacher attention between various targets in the classroom (McIntyre, Mainhard & Klassen,

2017). Expert vision is also visible in attempts to direct the shared attention toward contents in mathematical tasks, where expert teachers compared to novices focus on more relevant aspects that enhance a deeper understanding of mathematical contents (Pouta et al., 2020).

Through experience, the ways of scanning students and intervening in either single groups or the whole class become more advanced and effective (Cortina et al., 2015). Teachers have to make a decision whether to share their attention with all the students equally and observe everything in the classroom, or focus mostly on those students who are likely to need guidance. In Dessus, Cosnefroy, and Luengo's (2016) study, three out of four teachers chose the latter orientation, though looking at all students at least a few times during a mathematics lesson. Teachers' prior knowledge on students' mathematical abilities or social skills directs their attention (Dessus et al., 2016). Thus, high-quality feedback can be seen to correlate with the inequality of teachers' attention. The more a teacher focuses on giving feedback to certain students the less they can observe others (Cortina et al., 2015). An experienced teacher may also be able to handle the whole small group instead of individual students as one gaze target (Dessus et al., 2016). Contrary to this, Stürmer et al. (2017) relate uneven distribution of visual attention to novice teachers.

Teachers have distinctive attentional behavior between moments of attentional gaze (giving instructions) and communicative gaze (asking questions). Research finds the communicative gaze to be more dependent on the cultural context and teacher expertise (McIntyre et al., 2019). Teachers' communicative gaze guides the students' learning (McIntyre et al., 2017) by directing the students' gaze towards objects that are significant for the learning (Frith & Frith, 2012), as it includes information on the content (e.g. a picture on the board), but also on the values and interests of what is worth paying attention to (Csibra, 2010). Teachers may use gaze aversion for reflecting on the classroom situation and for short moments of cognitive relief, but also for conveying trust to students and offering them space and independence (McIntyre et al., 2019, see also Kendon, 1967). According to teachers' reflections, they relate eye contact to good teacher-student contact and highlight the significance of giving students a feeling of being seen. The sense of good contact is reciprocal: it includes the teachers' attention to students and the students' positive response to it (Korthagen, Attema-Noordewier, & Zwart, 2014).

3.3 EYE CONTACT IN INTERACTION

Eyes play a significant role in human interaction. The ability to notice attentional relation between people around us creates the basis of our social life (Böckler et al., 2016). Gaze is a significant social cue, and sudden eye contact towards us tends to capture our attention faster than an averted gaze (Böckler et al., 2014; Holmqvist & Andersson, 2017). A literature review on

gaze cueing states that eyes and their surroundings communicate emotional states effectively (Frischen, Bayliss, & Tipper, 2007). Gaze direction provides information on people's actions (eye-mind assumption: Just and Carpenter, 1980) and future intentions (Frischen et al., 2007). Dyadic eye contact helps in ensuring the relevance of our actions though the experience of others taking us into account (Kendon, 1967).

Eye contact and gaze cues have been researched in the field of psychology for a long time with numerous methods, such as neuroimaging (Böckler, Eskenazi, Sebanz, & Rueschemeyer, 2016), response time to visual cues (Böckler, van der Wel, Welsh, 2014; Dalmaso, Pavan, Castelli, & Galfano, 2011), verbal (Brey, & Shutts, 2015) or written (Zeki, 2009) experiences in social situations, and static (Gobel, Kim, & Richardson, 2015) and mobile (Schulz et al., 2010) eye tracking. Most of the research, for instance all the studies mentioned above, is conducted in laboratory settings.

Hessels (2020) has proposed a dynamic system approach to gaze in face-to-face interaction. According to this approach, gaze interaction is a combination of numerous sub-states at three different levels: interactor-specific (e.g. the aim of the interaction), content-related (e.g. gaze direction), and context-related (e.g. interpersonal context). In this model, the interactor-specific aspects exist within the participants of the interaction, the content-related between them, and the context-related around them (Hessels, 2020).

Already at the age of five years, children are able to interpret the social power of people in photos by observing their nonverbal behaviors, such as gaze (Brey & Shutts, 2015). In general, people tend to attend to pictures of those individuals whose social rank they estimate to be high to learn from them (Gobel et al., 2015). However, these results seem to be dependent on the methods of data collection. For example, when individuals of high social status are monitored through pictures, the research participants tend to follow their gaze cues more than of those individuals whose social status is perceived as low (Dalmaso et al., 2011). On the other hand, when the research participants believed that individuals of high social status would afterwards watch their gaze recording, they stared at the faces of these individuals with shorter fixations than at faces of individuals of lower social status (Gobel et al., 2015). Likewise, Akechi et al. (2013) found that people prefer shorter gazes from faces on a display showing direct eye contact than from those with averted gaze, and interpreted this to result from the experience of dominance that the direct face-targeted gaze transfers. In a large study with dual mobile eye tracking, the participants gazed at each other's faces approximately 60% of the time spent in getting-acquainted conversations, and these gazes lasted 2.2 seconds on average (Rogers et al., 2018). Thus, we can interpret that choosing the right method is crucial for examining the role of face-targeted gazes in social interaction.

With eye contact, people communicate experiences of communion, positive attitude, and warmth (Mehrabian, 1972). In social interaction, another person's friendly response to eye contact initiative increases the experienced

liking of that person (Frischen et al., 2007). The teacher's eye contact, as a part of nonverbal interaction, encourages students to interact (Roberts & Friedman, 2013). Additionally, students' perceptions of the teacher's attention to them correlates positively with cognitive and affective learning and with learning engagement in mathematics (Ellis, 2000; McCluskey, Dwyer, & Sherrod, 2017). While reprimanding students, nonverbal communication of immediacy is especially important (Babad, 2009). However, there is also evidence of teacher immediacy behaviors not influencing affective learning (Mottet et al., 2008).

Additionally, high teacher communion helps students to direct their attention towards learning goals (Bolkan et al., 2017). The reliability of the instructor as well as the conviction of the message increase with direct eye contact (Mehrabian, 1972; Zeki, 2009). Through eye contact, teachers communicate to students that they are in the locus of their attention and the instruction implicates them (Adams, Nelson, & Purring, 2013; Ellis, 2000; McIntyre, Mainhard, & Klassen, 2017). With gaze direction, the teacher can address to the students what is the object of the instruction and the meaningfulness of the matter ("I want you to pay attention to this") (Böckler et al., 2014). However, large classrooms challenge the visual teacher-student interaction, as the possibilities for efficient visual teacher-student interaction tend to decrease with a distance over five meters (Cardellino, Araneda, & García Alvarado, 2017).

Paying attention to student faces tends to increase the cognitive load of the teacher. This load is also high during transitions between tasks, while managing the class as a whole group, and while using tools that are novel to the teacher (Prieto, Sharma, Wen & Dillenbourg, 2015). However, the results on the effects of cognitive load on gaze behavior are somewhat contradictory. A study with surgeons with mobile gaze tracking challenges the previous psychological knowledge by suggesting that the cognitive working load affects the fixations by decreasing their duration (Schulz et al., 2010).

3.4 MOMENTARY TEACHER-STUDENT SCAFFOLDING INTERACTION

Scaffolding is adaptive interaction, and is thus relevant to be explored with moment-to-moment actions in real classroom contexts. One of the objectives of teachers' attention during collaborative problem solving is to receive information on the students' needs for scaffolding (van den Bogert, van Bruggen, Kostons & Jochems, 2014). Teachers' monitoring and ensuring that students understand, especially immediately before the fading phase of scaffolding, has been found to be crucial for the efficacy of scaffolding interaction in small-group learning (van de Pol, Mercer, & Volman, 2019).

The research on scaffolding interaction is moving towards continuous coding and in-situ descriptions. Traditionally, teacher-student scaffolding

interaction has been investigated by means of descriptive and observational small-scale studies (Van de Pol et al., 2010) and interventions (Bakker et al., 2015). Human agency and communion were originally researched as psychological traits, based on researchers' observations on psychotherapy patients' behaviors that were seen to represent fixed characteristics of personalities (Wiggins, 1991). Throughout the decades, the interpersonal theory has remained relevant. However, the research methods in education have developed, first into examinations with the Questionnaire of Teacher Interaction (QTI) on teachers or students' perceptions of teachers' interpersonal styles (e.g. Brekelmans et al., 1990; McIntyre, 2016) and in recent years toward exploration of the continuous changes of interpersonal behaviors captured by continuous coding (e.g. Pennings et al., 2018; Sadler, Ethier, Gunn, Duong, & Woody, 2009; Thomas, Hopwood, Woody, Ethier, & Sadler, 2014). When surveyed with QTI, teachers around the world prefer an interpersonal style that is leading, helpful, and understanding, that is, to use a variety of styles that are among the positive levels of teacher agency and communion (den Brok, Levy, Rodriguez, & Wubbels, 2002; Yu & Zhu, 2011). Teachers tend to see themselves in a more preferred interpersonal style than students rate them according to QTI scores (den Brok et al., 2002; Levy, Wubbels, & Brekelmans, 1992).

Sadler and colleagues (2009) have developed a method called Continuous Assessment of Interpersonal Dynamics (CAID) that "captures interpersonal dynamics as a continuous, contextualized flow of behaviour as it unfolds over time, based on continuous coding of videotaped behaviours" (Pennings et al., 2018, p. 44). In their multiple case study with the CAID method of teacher-student interpersonal adaptation, Pennings et al. (2018) found that teachers with preferred interpersonal styles were usually in the leading role in interpersonal adaptation in their classrooms, which led to students reducing their agency and increasing their communion during the teachers' instructions. Most teachers were also able to keep positive levels of communion even in moments of student hostility. Finally, and importantly, Pennings et al. (2018) found empirical evidence on the relation between teachers' interpersonal styles (traits) and momentary interpersonal behaviors (states). Teachers' interpersonal styles, as perceived by their students, were similar to the researchers' perceptions of their interpersonal behaviors in the classroom situations (Pennings et al., 2018). This result complements the work of Mainhard, Pennings, Wubbels, and Brekelmans (2012), who found a connection between teacher-student interaction and classroom social climate using State Space Grid coding. In their case study, Mainhard et al. (2012) found that during the observed lessons, interpersonal behavior varied more in classrooms with a less preferred social climate, whereas in classrooms with a more preferred social climate, the teacher's interpersonal behaviors were stable and positive (i.e. high communion and agency).

Scaffolding theory includes the principle of the transfer of responsibility, meaning that the students' agency should increase through the scaffolding

interaction (Stone, 1998). According to Interpersonal Theory, the complementarity of interpersonal behaviors should affect teacher agency by decreasing it while increasing student agency and vice versa (Kiesler, 1983). In addition to teacher and student agency, the aspect of human communion is also present and crucial in scaffolding interaction, for example from the perspective of the requirements of interpersonal interdependence (O'Donnel, 2006). In comparing novice and expert teachers, novices were found to express more intimacy (i.e. behaviors of communion) while scaffolding students, whereas expert teachers had the tendency to aim scaffolding at the whole group (Cortina et al., 2015).

Eyes both gather and communicate information in social interaction (Kendo, 1967; Risko et al., 2016). Capturing the reciprocity of classroom interactions is important for the development of the methodology of educational research. The CAID method of continuous coding of teacher interpersonal behaviors provides the opportunity to reach this situational social level in teacher-student interaction, while adding mobile gaze tracking to the data collection can provide a completely novel approach to educational research.

3.5 SUMMARY: THE PERSPECTIVE ADOPTED

Based on the theory of scaffolding intentions and Interpersonal Theory, and inspired by the state-of-the-art literature on teacher's visual attention and moment-to-moment interpersonal behaviors in classroom, this section synthetizes the perspective this dissertation adopted for examining teachers' gaze behavior (Figure 2).

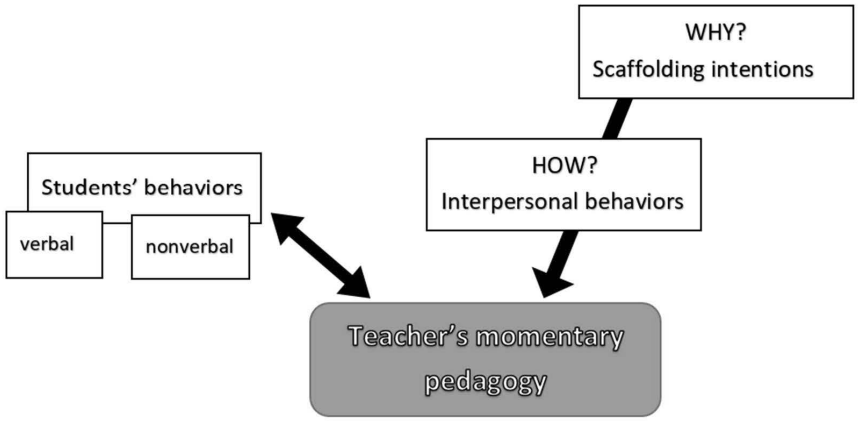

Figure 2 Theoretical background: Teacher's gaze behavior in problem-solving interaction

Instruction is intentional human interaction. In the context of mathematical problem solving, the teacher's objective is to direct the students' learning process by means of scaffolding (Wood et al., 1976). Cognitive, affective, and metacognitive scaffolding intentions direct the teacher's momentary pedagogical decision-making and the interaction with the students. With cognitive scaffolding, the teacher aims at simplifying and clarifying the problem to meet the abilities of the students. With affective scaffolding, the teacher prevents students from negative emotions that might disrupt the learning process. With metacognitive scaffolding, the teacher aims to direct student interaction and attention towards the learning contents and goals (van de Pol et al., 2010).

The teacher's scaffolding intentions manifest themselves in the teacher-student interaction. Teachers' behaviors of communion and agency form the in-situ scaffolding interaction. Based on the complementarity principle of interpersonal theory, these behaviors are are related to student behaviors, high communion evoking high communion behaviors and high agency evoking low agency (Kiesler, 1983).

Teacher-student interaction is reciprocal, and students need to be taken into account in interaction research as naturally they play an important role in the classroom interaction. Their knowledge and abilities affect the teacher's scaffolding intentions (van de Pol et al., 2010) and actions (Hermkes et al., 2018), and their behaviors of complementarity or non-complementarity influence the teacher's interpersonal behaviors (Gurtman, 2009; Sadler et al., 2009). Teachers and students communicate both verbally and nonverbally (Babad, 2009; Mottet et al., 2016), continuously interpreting and anticipating each other's interpersonal behaviors (Pennings, et al., 2018).

Teachers create their momentary pedagogy in interaction with students based on the teachers' intentions, and by means of interpersonal behaviors. Teacher visual attention reflects their pedagogical knowledge, values, and expertise (Csibra, 2010; Frith & Frith, 2012; McIntyre et al., 2017). In instruction interaction, teachers make continuous decisions on their gaze direction and distribution (Dessus et al., 2016). Direct gaze and eye contact conveys a person's agency (Gobel et al., 2015) and communion (Mehrabian, 1972). Teacher attention to students can improve classroom interaction (Roberts & Friedman, 2013), student engagement (Ellis, 2000; McCluskey, 2017), and the experience reliability of instruction (Zeki, 2009). However, the results on situational visual attention and eye contact communication seem to depend on the methodological choices, and the research community lacks information on gaze behavior in real classroom contexts.

4 THE AIMS OF THE RESEARCH

As mentioned before, earlier research on teachers' attentional processes and teacher-student interaction as well as interpersonal theory and theory on scaffolding intentions create a picture of the components constructing the teacher's moment-to-moment pedagogy in the context of collaborative problem solving. However, the full meaning of teacher gaze can only be understood if examined from an interactive perspective: attentional perceptions become a cultural symbol, as they are noticed and interpreted by other people, that is, the students (Goodwin, 2017). Therefore, the role of nonverbal behavior, especially visual attention and eye contact, in classroom interaction requires more profound investigation. These aspects impact in the classroom, and knowledge about them could help the research community to understand micro-level interactional processes, but could also benefit teachers in their professional learning. Figure 3 presents the basis of the research questions in this dissertation.

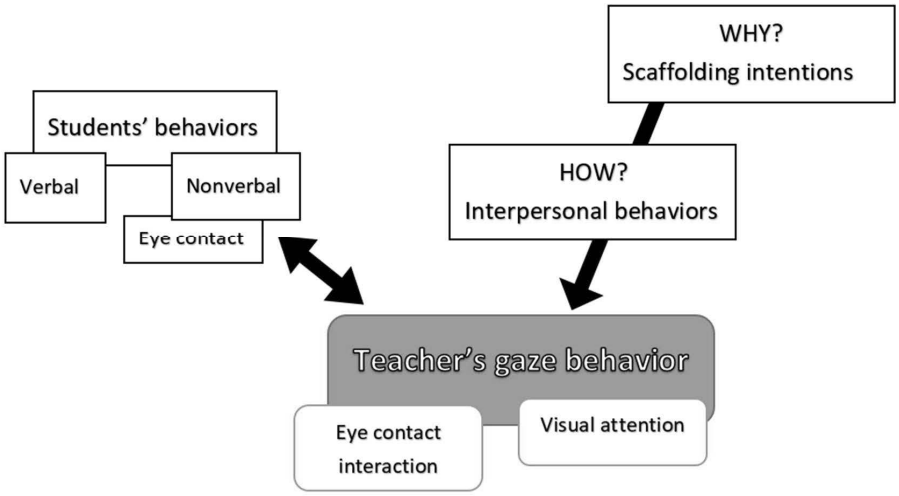

Figure 3 The aim of this research: How do scaffolding intentions, interpersonal behaviors, and student gaze affect the teacher's gaze behavior?

Most recent eye-tracking research examines teacher gaze from the perspective of teacher expertise, which is a quite static characteristic of a teacher. On the other hand, teachers' perceptions on momentary classroom events have been mainly investigated using static gaze tracking of classroom videos. This

dissertation brings the moment-to-moment perspective to both the method of data collection and to theory-driven analyses. From scaffolding theory, I used continuous coding of teachers' scaffolding intentions, and from Interpersonal Theory, teachers' momentary interpersonal behaviors instead of a teacher's interpersonal style. The gaze data were collected in authentic mathematics lessons using mobile gaze trackers on teachers and students to capture their in-situ gaze. Thus, this dissertation brings the educational eye-tracking research on teachers' gaze behavior to the next level of reaching toward the micro-processes that serve as the building blocks of teacher-student relationships.

4.1 THE GENERAL RESEARCH QUESTION

In the three sub-studies, I have examined (1) how the teacher's visual attention is distributed during scaffolding interaction with student collaboration groups, (2) in what ways do teachers interact with students in terms of eye contact during scaffolding interaction, and (3) how do teachers' momentary interpersonal behaviors relate with the occurrence and durations of eye contacts with students.

In general, this dissertation aimed at characterizing the role of teacher gaze in nonverbal classroom interaction in the context of problem solving. The analytical summary of the dissertation emphasizes methodological reflections and theoretical considerations more than those of the sub-studies. The general research question is formulated as follows:

How are teachers' momentary scaffolding intentions and interpersonal behaviors manifested in their gaze behaviors and what is the role of student gaze in momentary teacher-student eye-contact communication?

4.2 THE RESEARCH QUESTIONS OF THE STUDIES

To help explain the process of writing this dissertation, the research questions of the three sub-studies are presented before the general research question. Studies I-III are presented in chronological order in this dissertation, and thus they represent the scientific path through the original research questions that led to this dissertation.

Study I

1. How does a teacher's visual attention distribute among student-related gaze targets while scaffolding a problem-solving process?
2. How do teachers' momentary intentions of scaffolding direct their visual attention?

Study II

1. In what ways do teachers interact with students in terms of eye contact during collaborative mathematical problem solving?
2. How do the frequency and durations of teacher-student eye contacts differ across the teachers' scaffolding intentions?

Study III

1. What kind of connection is there between the teachers' momentary interpersonal behavior and the occurrence and durations of teacher gazes at their students?
2. How does the teacher's momentary interpersonal behavior relate to the occurrence and durations of student gazes at their teacher and student-started eye contact?

5 METHODOLOGY

The research design of this dissertation developed throughout the research process. The purpose of the dissertation was to chart an unexplored phenomenon of teachers' momentary visual attention and teacher-student eye contacts in the context of collaborative problem solving. Risko et al. (2016) suggested examining the phenomena of dyadic gaze behaviors by first exploring them in situ to unravel the general characteristics, and then extending the research to more controlled settings. However, instead of taking that direction, this dissertation narrowed its scope of investigation within the same data by moving from charting the targets of the teacher's visual attention during instructional interaction to zooming into the reciprocal gaze interaction between teachers and students.

As these research topics have remained unexplored until very recent years, I found it important to combine quantitative and qualitative analyses in order to have more comprehensive research results. I will argue in favor of this decision in section 5.1. The subsections that follow present the larger research project of which this dissertation was part (5.2), its participants (5.3), apparatus (5.4), research setting (5.5), and the analytical methods used in the sub-studies of this dissertation (5.6).

5.1 MIXED METHODS APPROACH TO MOBILE GAZE TRACKING

Mixed method research designs provide researchers with possibilities to explore and conceptualize complex and multidisciplinary research topics (Bergman, 2018). In educational eye-tracking research, quantitative methods can provide information on teachers' perceptional patterns, and qualitative analyses can deepen this understanding with detailed reflections about gaze behavior at an individual or group level (Beach & McConnel, 2019). With triangulation, empirical research aims toward an in-depth understanding of the phenomenon through interpretations that may be thick and complex (Denzin, 2012). This research includes theoretical triangulation by using scaffolding theory, which is mainly educational, and Interpersonal Theory, which stems from the psychological background. Thus, using a mixed method approach was not only justified, but also necessary.

As already shown in the literature review, collecting gaze tracking data in a naturalistic environment affects the apparatus, research questions, and interpretations. Holmqvist and Andersson (2017) have discussed the face-to-face paradigm in eye-tracking research as distinct from interactional research with video stimuli. In the face-to-face paradigm, the participant's attention at other person's facial and gestural cues either in relation to situational or static

aspects of human interaction is in the locus of the research (Holmqvist & Andersson, 2017). The research setting in the research project, of which this dissertation is part, even goes beyond what the face-to-face paradigm assumes. The challenge of the paradigm lies within the reciprocity of eye contact interaction. As mentioned before, human eyes both collect and convey information in interaction (e.g. Gobel et al., 2015), which sets challenges for interpreting the gaze data. Thus, in interaction, the participants are the stimuli and vice versa (Risko et al., 2016). This argues for the way we used gaze tracking: with multiple gaze trackers simultaneously in authentic classrooms, where the participant teachers led the scaffolding interaction in the way they preferred, and synchronizing the recorded gaze data with the video data on scaffolding interaction for a more comprehensive understanding of the nonverbal in-situ communication.

The studies of this dissertation used recordings from three lessons, and specifically the teachers' interaction with small groups during the collaborative phase of the problem-solving lessons. I chose these phases due the richness of the teacher-student and peer interaction. The nature of the data enabled within-individual analyses in the light of the social level of scaffolding. The social level of scaffolding is present in all three sub-studies. Even though I use gaze data from only one teacher (individual level) in Study I, the reflections on his visual attention are relative to his verbal and nonverbal interaction with the collaboration groups (social level). In Studies II and III, the student gazes are also included. The social level is particularly present in Study III, where the qualitative example excerpts combine group-level interactional data with gaze data from all the participants. Hence, the paradigm of this dissertation is a face-to-group one.

In our research setting, we use triangulation of data sources. The gaze recordings are complemented with two kinds of verbal data: stationary classroom video recordings and stimulated recall interviews after the session. The classroom videos were synchronized with the gaze data for the qualitative coding and analyses. The gaze-tracking data maintains all the details of visual attention during the recording, and hence the reflections stimulated by this data "can help in producing information that cannot be obtained by traditional techniques alone" (Hyrsykari et al., 2008). The stimulated recall interview, where the teacher watched his classroom video and his gaze recording, served as background data in Study I to confirm the qualitative analyses. To reach enough validity for educational interpretations on gaze data, complementary verbal data is necessary. Especially stimulated retrospective reflections have proved to be useful in deepening researchers' understanding of gaze recordings (van Gog et al., 2005).

The nature of our data also supports the use of analytical triangulation. The gaze recordings include both qualitative and quantitative information. In spite of the exploratory nature of this research, I chose to use quantitative methods to make sense of the data. Gaze tracking provides us with huge amounts of data. This data can be charted with descriptive statistical analyses to draw the

general picture of situational gaze behaviors in relation to the pedagogical and interpersonal variables. Additionally, gaze data includes qualitative information, as the researchers can follow the recording and make interpretations on the gaze direction of the participant. This could be done with a wide or narrow scope, depending on the research question. I chose to code all teacher gazes during the collaborative phases of the mathematical problem-solving lessons. Complementing gaze data with other forms of (qualitative) data is very common in social studies. These methodological decisions will be reflected upon in detail in the following sections.

5.2 THE MATHTRACK PROJECT

The MathTrack research project (2016-2020) was based at the Faculty of Educational Sciences at the University of Helsinki. The research team included mathematics education researchers from the University of Helsinki and several collaborators around the world. MathTrack was funded by the Academy of Finland (grant 297856) and led by Professor Markku Hannula. The aim of the project was to examine classroom interactions with the focus on the complexity of the social and embodied processes of learning, gaze behavior in the classroom context in particular. The project was a continuation of the research tradition on affects in mathematical learning and mathematical problem solving at the University of Helsinki. It provided new insights into the continuous self-regulative processes of collaborative problem solving that are difficult to capture by more traditional means of data.

Overall, the research data consisted of pilot data with teacher students and seven actual data collections with ninth-grade students and their mathematics teachers. The project has charted the general patterns of teacher and student attention. Developing analysis methods for the gaze data has also been at the heart of the research (Garcia Moreno-Esteva et al., 2020; Toivanen, Lukander & Puolamäki, 2017). Other paths of exploration include student gaze interaction (Salminen-Saari et al., submitted for publication) and visual attention (Hannula, Toivanen, & Garcia Moreno-Esteva, 2019), student attention at teacher gestures (Koskinen-Salmia, Haataja, Salonen, Toivanen, & Hannula, manuscript in preparation), and task dependent teacher gaze (Määttä, McIntyre, Ihantola, Scheinin, & Hannula, manuscript in preparation).

Due to the nature of our data, ethical considerations were central in the project. The research procedures of the project have been subjected to an ethical review and were approved by the University of Helsinki Ethical Review Board in the Humanities and Social and Behavioral Sciences. As the research subjects were comprehensive school students and their teachers, I find it necessary to consider the ethical issues from their point of view. Two ethical issues emerged from the use of gaze tracking glasses. First, these glasses were made to be as functional as possible without being uncomfortable.

Nevertheless, the glasses restricted the subjects' visual field. This was advantageous for the quality of the data, but may have been annoying or uncomfortable for the research subjects. Some of the subjects reported that they felt that the device was heavy, squeezing, or pinching. The researchers always helped the subjects adjust the glasses when wearing them and encouraged them to say if they felt at all disturbing. However, the data collection sessions may have been exciting, especially for the students, and we were unable to guarantee an atmosphere which was open enough for anyone to raise issues of discomfort out loud. This problem has emerged in earlier mobile eye-tracking studies as well (e.g. Brom, Stárková, Lukavský, Javora & Bromová, 2016), and will probably diminish as the eye-tracking technology develops. Fortunately, the data collections only lasted for one lesson, and the participants were always able to take the glasses off if they wished.

Secondly, as we made our recordings during complete lessons (45 minutes), we recorded our participants' visual attention which is, at least to some extent, unconsciously (Tatler et al., 2014). Even though humans direct their attention, they may not be able to control their gaze during a long period in an interactively versatile situation. In comparison, in an interview situation, the subjects could choose what to include and exclude in the conversation. The eye-tracking data, however, might include sensitive material. Thus, we exercised discretion when working with and analyzing our data, and when publishing our results. For example, adolescent students sometimes looked at each other's bodies. In my analyses, student and teacher bodies and hands shared a common code, and, due to the research questions that directed the analyses and were pedagogical in nature, it was not of interest to me to analyze the purpose of the gazes at separate body parts but only to separate them from the gazes at faces and students' belongings.

5.3 PARTICIPANTS

The data for this thesis consist of recordings in three mathematics lessons in three lower secondary schools in the Finnish capital area. Conducting eye-tracking research in middle school is relatively rare (Strohmaier et al., 2020). Our participant classes represent the oldest age group of the Finnish lower secondary level. The MathTrack project team recruited teachers and classes for the data collection based on the school's accessibility and the teachers' voluntariness. All the participant teachers were qualified mathematics teachers and the classes were general education 9th grade classes. In Finland, 9th grade students are 15-16 years of age.

We collected written permissions for the data collection from the schools' principals. Additionally, we informed the students' parents about the research. Aligned with the ethical guidelines of The Finnish National Board on Research Integrity TENK, we interpreted the 9th graders to be old enough to decide on their own whether to take part in the research. The researchers carefully

introduced the procedure to the participants at the beginning of the first data collection lesson. Subsequently, we collected consent forms from all students and teachers in the classes. As an acknowledgement of their contribution, the classes received small contributions to their school trip accounts and the target students and the teachers received gift cards. To ensure students' and teachers' anonymity, I have used pseudonyms when referring to them. The only restriction in the selection of target students and teachers had to do with having normal eyesight without glasses to guarantee the functionality of the gaze tracking devices.

From the seven participant teachers, I selected three teachers, Joanne, Fred, and Lily, who represented different levels of expertise. The data collection with Joanne (middle-career) and Fred (novice) took place in the spring of 2017 and with Lily (experienced) in the winter of 2018. I was personally present in Lily's data collection.

On one hand, my small sample size can be seen as a limitation of this research, as it often is in eye-tracking studies in education (Beach & McConnel, 2019). On the other hand, the restricted number of participants made it possible to construct a comprehensive and precise picture of their gaze behavior. The data provided me with a fascinating opportunity to explore the perceptions and momentary pedagogical and interpersonal behaviors of three different and unique teachers.

Joanne was 39 years old and had 14 years of teaching experience at the time of the data collection. Joanne's school was in an urban area with high socio-economic status. Observations of the lessons showed that her students were well behaved and quite capable in mathematics. Joanne's class contained seven boys and twelve girls. They were seated in pairs and, during the collaborative phase of the lesson, formed five groups of three to five students. The four collaborating target students wearing gaze-tracking glasses in Joanne's class were girls.

Fred was 30 years old with three years of experience in teaching mathematics. Fred worked in a school located in a suburban neighborhood of high socio-economic status. Fred's class included eleven boys and eight girls. The students' mathematical abilities and motivation were diverse. The students sat in pairs and, during the phase examined in this thesis, worked in five groups of two to four students. One student in Fred's class chose not to participate in the collaborative learning phase of the lesson and was instead given personal tasks. The four focus students wearing the eye-trackers in Fred's class were boys. Due to a malfunction in one of our devices, we were able to use the gaze data of only three students from this lesson.

Lily was 56 years old and had 31 years of teaching experience. Lily's school was situated in a suburban area of low social-economic status. Many of her students were not native Finnish speakers and some needed extra support with mathematical contents. The interaction in the class was humorous and spontaneous. On the day of the data collection, Lily had only six boys and three

girls in her lesson. The target group was made up of three boys and one girl. Lily's students sat in groups of four, three, and two.

5.4 THE APPARATUS

This subsection presents the gaze tracking devices used in this study and reflects on the ethical and methodological questions related to their use. The studies of this dissertations used dwell as a coding unit. By a dwell I mean one visit to a gaze target from entry to exit (Holmqvist & Andersson, 2017). Dwells differ from fixations and saccades not merely in durations and occurrences, but also in the interpretations that can be made from the data. Fixation durations and proportions of the total dwell time on targets are subject to various psychological variables, such as emotions, cognitive load (Schulz et al., 2010), or the obscurity of the stimulus (Holmqvist & Andersson, 2017), as well as the bottom-up circumstances in the situation (Frischen et al., 2007). Measuring the dwells, however, reaches towards understanding the top-down processes of visual attention (see Holmqvist & Andersson, 2017). I chose to analyze the data in terms of dwells to capture the conscious attentional behaviors of the teachers, and thus their pedagogical vision.

Five gaze-tracking glasses recorded the eye movements of the teacher and the target students. The device was designed at the Finnish Institute of Occupational Health (Toivanen et al., 2017). The eye-tracking device consists of two eye cameras recording the eye movements, a scene camera recording the environment, and infrared LED lights attached to 3D-printed goggles. The eye cameras detect the reflections of infrared lights on a person's iris. Using these reflections and the information from the personal calibration of the device, the apparatus forms a 3D model of the eye and is able to follow its movements (Toivanen et al., 2017). The accuracy of the device is approximately 1.5 degrees of the visual angle, which makes it more accurate than many devices on the market (Strohmaier et al., 2020). Still, the existing error highlights the importance of careful and well-justified interpretations when analyzing the data (Strohmaier et al., 2020). The apparatus also includes a corresponding software that calculates the target of the visual attention on the scene being recorded and creates a new video that shows the target as a circle on the scene video. The software also estimates the momentary accuracy of the eye movement recordings, and adapts the size of the circle accordingly: the smaller the circle, the more accurate the target of the gaze. When the cameras do not record the pupil, for example when participants close their eyes, take off their goggles, or direct their gaze outside the scope of the eye-tracking cameras, the software shows the text BLINK on the video data. The laptop computers that processed the data were located in backpacks worn by the participants during the lesson. This enabled them to move freely in the classroom.

The data collection with head-mounted gaze trackers requires some special reflection from the perspective of the participants. The goggles that our participants wore may not have been comfortable all the time, even though the objective of the development process has been to produce glasses that are as well fitting and functional as possible. The shape of the goggles of the device increased the quality of the data, as they made peripheral gazes impossible. Our research participants reported that the goggles restricted their visual field, and some students experienced pressure from the goggles, but were still willing to continue wearing them until the end of the lesson. According to earlier research, glasses may cause feelings of irritation, stress, or even embarrassment (Brom, Stárková, Lukavský, Javora, & Bromová, 2016; Magnussen et al., 2017). In our research setting, the target students in each class worked in a single collaboration group, in which all the students wore the goggles. Thus, the students, whose gaze data we used, collaborated mainly with other students wearing the gaze trackers as well. They had also tried on the goggles in the first, preliminary data collection lesson, which we hope decreased the awkwardness of wearing them.

The gaze trackers may have an impact on the social interaction, as the obscurity of the person wearing the glasses can affect the willingness of the others to interact (Magnussen et al., 2017). To preclude this from affecting the results too much, it is important that the time periods during which the glasses are worn are long enough for the participants to get used to wearing them. Previous research shows that the awareness of the eye tracking affects the participants' gaze behavior for less than two minutes at the beginning of the lesson (Praetorius et al., 2017), but disappears as the participants get used to wearing the glasses and forget about wearing them (Praetorius et al., 2017; Risko et al., 2016).

Due to the sensitive nature of our data, we handled them with extreme care. The research questions always directed their examination, and the gaze targets that were not relevant for the research, such as the contents of the students' personal phone displays, were not examined during the analysis process.

Magnussen et al. (2017) suggest that researchers should seek to minimize the interventional nature of mobile gaze tracking data collections in order to ensure the validity of the data. I partly agree and admit that this probably was not the case in our research setting. The apparatus and mounting, calibrating, and taking care of it required time and space in the classroom. However, becoming familiar with the research equipment and the work of a research group from their local university was also an intriguing experience for students planning their future studies at the end of their comprehensive school. We are still technically far from devices that would be so discrete that participants would completely forget about them during the data collection (and I am not sure whether that kind of development would be an entirely good direction ethically). Thus, we have to accept the fact that all methods of moment-to-moment data collection somehow affect the data. Mobile gaze tracking offers us information that would be impossible to obtain with post-lesson stimuli. In

their article, Xu, Widjaja, and Ferguson (2017) have reflected on the researcher's role in affecting classroom actions. They collected data with a GoPro camera mounted on the teacher's head and then left the room so that the lesson could proceed without their interference. They argue that traditional observation studies on video recordings show the view of the classroom events that is defined by the researchers, and giving the cameras to the teachers offers them the agency to choose what is seen on the videos (Xu et al., 2017). We remained in the classrooms throughout the data collection lessons, supporting the teacher with any possible issues to do with technical devices and the problem task we had proposed.

However, our participants were "the directors" of the gaze-recording videos and their vision directed my research questions, analyses, and writing of research reports. Traditionally, it has been the researcher who records the lessons, chooses the video clips and perspectives, and creates the interview frame for the post-lesson reflections. In this way, the authority in the reflection remains with the researchers, whereas mobile gaze tracking offers the possibility to transfer the agency to the teachers (Xu et al., 2017). When wearing the gaze tracking glasses, the teachers are the directors of the classroom recordings, and share their world and vision with the researcher in the stimulated recall interviews. The interview frame was created by the researchers in the project, but it was quite loose and gave the teachers space to outline their reflections.

In addition to the gaze trackers, we recorded the actions and conversations of the problem-solving sessions using three stationary video cameras in the classroom. One camera followed the teacher and two were directed at the collaboration group of target students. To ensure the quality of the audio recording, the teachers wore personal microphones and the written notes and speech of the target students were recorded with Smartpens. After the sessions, all these visual and audio data sources were synchronized.

5.5 RESEARCH SETTING

The research group visited two mathematics lessons of each class. The purpose of the first lesson was to inform the participants about the research setting, collect the written consent forms, test the apparatus, and calibrate the gaze tracking devices in the naturalistic environment. The first lesson also allowed the participants to become acquainted with the equipment.

The actual data collection and the collaborative geometry problem solving took place during the second lesson. The lessons started with general instructions and checking the previous homework. Then the teachers introduced the problem task and the students started to solve the problem individually. After a short stretch of individual work, the students continued working in pairs, and shortly after that in small groups. This phase, called the collaborative phase, is the phase in which I focused on the study presented in

this dissertation. After the collaboration phase, the students went on to present their solutions on the blackboard. The stimulated recall interviews with the teachers and target students were conducted after the second lesson. In the following, I present the problem task and the course of the lessons in detail.

The objective of the problem task was to obtain the optimal solution to a geometry problem (Steiner tree problem for four points). The teachers received the following task instructions to present to their students:

> *Here is the task. In the picture you have four cities; they lie on the corners of a square. You have most likely seen how two places are connected by cable or optical fiber. First, work alone and try to find at least three different ways in which the cities might be connected. Think which of these is best. Can you think of a better solution? You will have five minutes to work alone and I will tell you when to form pairs. --- Now work in a pair and discuss what is the most effective way to connect the four cities so that the least amount of cable is used – that is, so that the total length of the connections is as short as possible. --- Form groups of four and continue searching for the best possible solution.*

Figure 4 shows three example solution drawings in a student's notebook. The furthest on the right is what we call the optimal solution. Even though it is a free hand drawing, it provides an idea of something that could be confirmed to be the optimal solution by measuring with a ruler.

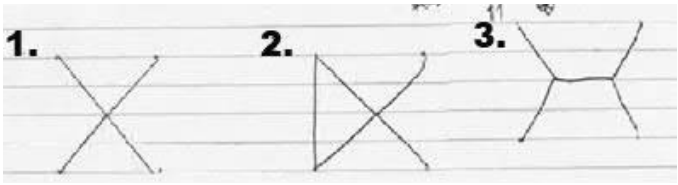

Figure 4 Three solutions to the geometry problem task in a notebook of Joanne's student. The draft of the optimal solution is number three.

The researchers instructed the teachers to support their students during the problem-solving process without funneling (see Anghileri, 2006) information to solve the problem. All the teachers encouraged the students to share the solution drafts with each other and discuss them, and finally to select the solution they preferred to be presented to the rest of the class. During the collaborative problem-solving phase, the teachers' activity consisted of moving around the classroom and stopping to scaffold one small group at a time. In this dissertation, I refer to these moments of teacher-group scaffolding interaction as scaffolding events. Joanne gave more whole-class instructions during the collaborative phase than Fred or Lily. Additionally, Joanne and Lily instructed their students to move around the class to observe the solutions of

other collaboration groups, whereas Fred did not. The collaborative phases lasted about 18 minutes in Joanne's, 16 minutes in Fred's, and 17 minutes in Lily's class.

The students were free to negotiate the methods of solving the task. The tools used for the problem solving varied between the classes. In all three classes, the students were allowed to use paper, pencils, rulers, and calculators. In addition to these, Joanne and Lily used GeoGebra software. In Joanne's class, GeoGebra served in the last, teacher-directed confirmatory phase of the problem solving. In Lily's class, the students used GeoGebra throughout the lesson. Hence, in this study, only Lily's data include the use of GeoGebra on laptop computers.

For Study I, I used data from Fred's stimulated recall interview. Watching the classroom video and his own gaze-tracking video, Fred reflected on and explained the actions and thinking during the scaffolding interaction. To give him a possibility to reach deep descriptions of his intentions uncorrupted by the researcher's conceptions (Meier & Vogt, 2015), Fred was encouraged to pause the recording whenever he wanted to and reflect on the contents he found important for as long as he wished with the help of the researcher's clarifying questions. Thus, the interview procedure was a semi-structured conversation. Fred was interviewed by another researcher in the MathTrack team and I transcribed and analyzed the interview recording.

Stimulated discussions are not just noticing events on the video, they include professional learning as well as critical (Xu et al., 2017) and metacognitive reflection (van Gog, Paas, van Merrienboer, & Witte, 2005). Nevertheless, interpreting and reflecting on classroom events and perceptions of them is a challenging task, especially for novice teachers (Wolff et al., 2016; Wolff et al., 2017). Expert teachers' post hoc interpretations on the perceptions of classroom events are more reflective about interpersonal reasons for actions than those of novices, who tend to verbalize merely what they saw (Wolff et al., 2017).

To summarize the characteristics of our research setting, we standardized several of its aspects. The setting of the data collection equipment and the seating of the students were similar in all three sessions used in this dissertation. The course of the lesson included the same phases and the researchers gave the same instructions to all classes. The content of the lesson (the problem task) and teacher instructions were also similar in all sessions. After the lesson, all target students and teachers participated in stimulated recall interviews, even though I used only one of the interviews. In addition to standardized factors, the participant teachers and students brought the research setting to life and gave the separate data sets their unique character.

5.6 ANALYSIS

In this subsection I will discuss the decisions regarding data analyses I made during the research process. First, I present the general principles of coding and analyzing the data. Subsections 5.6.1, 5.6.2, and 5.6.3 explicate the analysis processes related to sub-studies I-III. In order to analyze the gaze and classroom video data, I used continuous coding. With continuous coding we can reach the dynamics of micro-level processes of teacher-student interaction (Pennings et al., 2018) and make predictions and explanations of the behaviors of teachers and students (Schmitz, 2006). With ELAN software (Lausberg & Sloetjes, 2009), I manually coded the teacher and student gazes with a dwell as a coding unit. As mentioned before, a dwell is a single gaze visit on a specific target (e.g. face) that consists of one or more fixations (Holmqvist & Andersson, 2017). The case study approach enabled me to combine inter-individual with within-individual variation and report the situational changes rather than general patterns of gaze behavior.

5.6.1 CODING THE TEACHER GAZE

Visual attention consists of gaze targets and gaze durations (Holmqvist & Andersson, 2017). I used the dwell durations and occurrences to characterize the gaze behavior of the participants. *The gaze targets* are defined by the researcher and are often called areas of interest. I used three-digit codes to refer to them. For example, gaze code A1P referred to student 1 in collaboration group A and his solution paper (P), and C2F referred to the face (F) of student 2 in collaboration group C. The basic principle was to code with higher accuracy those targets that contained information on teacher-student interaction and the teacher's pedagogy, while coding the less informative targets with less accuracy. Careful selection of the targets and their boundaries is crucial for valid scientific interpretations and is directed by the research questions and paradigms (Holmqvist & Andersson, 2017). For educational research questions, separating the student's face from the rest of the body proved to be essential and adequate. As my research questions concerned pedagogical interaction rather than learning outcomes, I did not code all the student solutions separately like many others in our research project, but handled the student papers as one gaze target. The rest of the students' belongings (pencil case, head phones, etc.) and the desk surface were coded separately but analyzed as a shared target "desk & objects." Likewise, in these analyses the classroom furniture and walls, the researchers, and research equipment are handled as one shared code "other."

In addition to the qualitative information on the gaze target, the dwell codes included quantitative information on *the gaze duration*. I annotated all the dwells that appeared in at least three frames (i.e. the dwell > 80 ms, frame rate 25 frames per second) with distinctive codes according to the gaze targets. The duration of 80-90 milliseconds is considered to be the shortest fixation

that humans can control and process cognitively (Galley et al., 2015; Holmqvist & Andersson, 2017). Fixations shorter than that serve in the general perceptional process but the individual is unaware of them (Galley et al., 2015).

The durations of the dwells resonate with the complexity of the target and the depth of the teacher's processing while looking at it, whereas the occurrences (number) of the dwells convey the significance of the target (Glöckner & Herbold, 2011; Holmqvist & Anderssson, 2017) in teacher-student scaffolding interaction. The durations and occurrences are examined both as such and as proportions of the total visual attention. The total dwell times of the collaboration phases were 817 839 milliseconds (~13 min 37s) with Joanne, 843 617 milliseconds (~14 min 3 s) with Fred, and 935 702 milliseconds (~15 min 36 s) with Lily.

The data on gaze durations is often somewhat unfit for statistical analyses such as ANOVA. The nature of human gaze behavior causes skewness and the existence of outliers (Henderson, 2011; Holmqvist & Andersson, 2017). Our data were aligned to this, as they were skewed to the left, including more dwells that were short than long. The kurtosis was also quite high, as the number of moderately long dwells was very high in comparison with the number of short and long dwells. After discussing this issue with colleagues, I chose to use logarithm transformation to reduce the skewness and kurtosis of the data. After this, the data still failed the Levene's normality test, but the skewness and kurtosis had decreased to a range that is generally agreed to tolerate the use of ANOVA.

The coding protocol was similar to many previous studies (e.g. Hanley et al., 2015), despite the exclusion of coding of saccades between fixations. I chose dwells instead of fixations, as the research questions focus on the nature of the teacher's visual attention and teacher-student nonverbal interaction, rather than the teacher's cognitive or emotional processes or load. For the same reason, I excluded the saccades and one-frame-long fixations (transitions, see Holmqvist & Andersson, 2017) between the dwells from the coding. Analyzing gaze types (e.g. scanning vs. fixating) or eye movements were not within the scope of this research (cf. Holmqvist & Andersson, 2017; McIntyre, 2016). However, all the dwells during the collaborative phase of the lesson were included in the coding. Hence, the coding was comprehensive from the attentional perspectives, but not from the behavioral perspective. From this perspective, this study is more fine-grained than the body of educational eye-tracking research that tends to separate only a few areas of interest in the classroom.

The use of a dwell as a coding unit probably meant that our data included more outliers than would be the case if the data were coded by fixations. The teachers gazed at some targets, especially student papers and student gestures pointing at them, with long gazes that sometimes lasted for several seconds. Teachers' interpersonal behaviors also included some outliers, as the teacher behavior was coded to be (0, -1000) when no interpersonal behaviors occurred

(e.g. short moments of the teacher reading the instruction paper). Once again, the mixed method approach was essential for understanding this kind of data comprehensively. I excluded the outliers from the statistical analyses, but reflected on them in the qualitative descriptions.

Table 1 presents the quantitative analysis methods used in the sub-studies. These analyses and the quantitative descriptions are examined in the following sections, one study at a time.

Table 1 Statistical analyses used in sub-studies

	Video coding	
Gaze coding	Scaffolding intentions (Studies I & II)	Interpersonal behaviors (Study III)
Occurrence	Chi-square with Bonferroni post hoc	ANOVA with Bonferroni post hoc
Gaze duration	ANOVA with Bonferroni post hoc	Pearson's correlation

5.6.2 THE ANALYSES IN STUDY I

Study I became my first article, and my first goal was to familiarize myself with our data. First, I coded teacher gazes according to the protocol presented above (3.6). Secondly, I separated the scaffolding interaction from other forms of classroom interaction (e.g. teacher scanning the whole class) using the stationary classroom video recordings. I divided the teacher's verbal scaffolding interaction into five categories that arose from scaffolding intention theory (van de Pol et al., 2010). The categories were *cognitive scaffolding* (mathematical, structuring and adapting the problem task), *affective scaffolding* (emotional or motivational issues), *metacognitive scaffolding* (directing students' attention and interaction, advice on the procedures of the problem-solving process), *monitoring* (teacher scanning the group to get an idea of what stage they were at during the problem-solving process), and *fading* (final scanning of the group before leaving). With monitoring and fading I refer to the teacher's visual attention during moments without verbal interaction. Monitoring usually occurred at the beginning of the scaffolding events but also briefly during them, when the teachers followed student actions or discussions silently. Parallel to the monitoring phase at the beginning, fading refers to the teacher's intention at the end of the events.

After the annotation of scaffolding intentions, I exported the data to Microsoft Excel 2016 and IBM SPSS Statistics 24 software for further analyses. I used Excel to organize and form a descriptive picture of the data and SPSS for the statistical analyses. To answer the first research question, I compared

the occurrences (N = 1384) and mean durations (M = 470.55 ms, SD = 762.38) of teacher gazes with scaffolding intention categories. I analyzed the occurrences with mean comparisons and a Chi-square test, and the gaze durations with analysis of variance using a post hoc test with Bonferroni correction.

For the second research question, I combined all three data types (gaze, video, and interview data). The aim was to use qualitative descriptions to illustrate the teacher's momentary visual attention in relation to his scaffolding intentions. I selected four scaffolding events from the lesson. These events represented either cognitive, affective (two events), or metacognitive scaffolding. I chose events based on the clarity and unambiguousness of the scaffolding intention in interaction. The teacher's descriptions on the stimulated recall interview recording also provided confirmation of the interpretation of the scaffolding intentions for these events. Together with the second author of the article, we formed timelines to illustrate the moment-to-moment scan path of the teacher's visual attention. I also added bar charts to visualize gaze proportions during the selected scaffolding events.

5.6.3 THE ANALYSES IN STUDY II

For the second article, I first selected two more teachers for the investigation and selected the teachers' face-targeted dwells for further investigation. I divided these dwells into two categories: one-sided teacher gazes at student faces, and dyadic eye contacts. After this, I divided the dyadic eye contact dwells into two categories according to the initial part. Thus, I had three gaze categories: (1) *a teacher gaze on a student face*, (2) *a teacher-started dyadic eye contact*, and (3) *a student-started dyadic eye contact*.

This article was purely quantitative. For the statistical analyses on IBM SPSS, I used the same scaffolding categories as in Study I. I first formed an overview of teacher-student eye contacts with descriptive quantitative analysis. I used bar charts to illustrate the occurrences of the gazes at different targets and the distribution of the initiative parts of the dyadic eye contacts. After that, I analyzed the relation between the occurrence of the eye contact categories and the teachers' momentary scaffolding intentions with crosstabs and Pearson's Chi-square test using Bonferroni-adjusted pairwise comparisons with expected cell counts. I used two-way analysis of variance to compare the main effects of gaze durations for teacher persons, scaffolding intentions, and eye contact types.

During Lily's lesson, some technical issues took up some of her time. Thus, she had to pay attention to non-pedagogical targets, such as the researchers, as well as to the student laptop computers, while she solved the problems that ensued. This may partly explain the high proportion of student gazes towards her when compared to other teachers.

5.6.4 THE ANALYSES IN STUDY III

After Study II, I was motivated to carry out a deeper study of teacher-student eye contact communication, and I used the same teacher gaze data as in Study II. I wanted to examine the reciprocal character of teacher-student eye contact communication and I added student gaze data by coding the student gazes targeted to teacher faces with ELAN software. Hence, I had four gaze categories instead of the previous three: (1) a teacher's gaze at a student face, (2) a teacher-started dyadic eye contact, (3) a student-started dyadic eye contact, (4) *a student's gaze at a teacher's face*.

I wanted to analyze eye contact as part of teacher-student nonverbal communication, and chose to use Interpersonal Theory (Leary, 1957) as a starting point for conceptualizing the interaction. Together with the second author of the article, we coded the teachers' interactional behaviors using Sadler's established Computer-Joystick Method (e.g. Lizdek, Sadler, Woody, Ethier, & Malet, 2012; Sadler et al., 2009). Several studies in the fields of psychology (e.g. Thomas, Hopwood, Woody, Ethier, & Sadler, 2014) and education (e.g. Pennings et al., 2018) have validated this Computer-Joystick Method.

The idea of the method is to determine the participants' momentary behaviors of Agency and Communion with continuous coding by moving the cursor with a joystick on Cartesian coordinates. The x-axis represents Communion, ranging from hostility (-1000) to friendliness (1000), and axis y represents Agency, ranging from submission (-1000) to dominance (1000) (see Sadler et al., 2009; Wiggins, 1991). After the first coding, we compared the coding and noticed some moments where our interpretations did not agree. We looked into previous research for insight and discussed the inter-rater divergences in coding. After this, we conducted the coding again. After the second coding, we calculated the inter-rater reliability with interclass correlation on teacher communion (.641 with a 95% confidence interval from .624 to .658, $F(1, 6620)= 26.18$, $p < .001$) and on teacher agency (.913 with a 95% confidence interval from .909 to .917, $F(1, 6620)= 21.22$, $p < .001$). We also compared our coding qualitatively, and found that our disagreements were rather about the intensity of certain behaviors than about their direction.

After this, I used statistical analyses to compare teachers' interpersonal behaviors and the teachers and students' gaze behavior. The joystick method software marks the coordinates using half-second intervals. To compare these scores to gaze behaviors, the second author of the article helped me divide the gaze codes into half-second intervals. I compared the scores of teachers' momentary agency and communion with the occurrence of eye contacts using analysis of variance. The dwell durations and teacher agency and communion were compared using Pearson's correlation.

This study used analytical triangulation, as in Study I. As this study is, to my knowledge, the first study using multiple mobile gaze data to explore reciprocal teacher-student interactions in an authentic classroom, I felt it necessary to examine the phenomenon qualitatively as well. For the qualitative

descriptions, I looked for moments in the transcribed classroom videos that represented interpersonal teacher behaviors typical of the different gaze types. I did this by looking for moments with certain gaze types and levels of teacher communion and agency within the standard deviation from the mean in the category. I interpreted the interaction in these excerpts in the context of the whole lesson to describe the momentary gaze behavior. For readability, the article uses density heatmaps, created by the second author, and tables to illustrate these somewhat complex analyses.

6 OVERVIEW OF THE STUDIES

The overall aim of this dissertation was to examine how teachers' momentary scaffolding intentions and interpersonal behaviors are manifested in their gaze behaviors and how the students respond to them. The dissertation consists of three empirical studies, each of which explored teacher gaze behaviors, comparing the occurrences and durations of gaze dwells with teachers' pedagogical actions and behaviors. In this chapter, I will present the main findings of each of the sub-studies. Further details are available in the original publications.

6.1 STUDY I: TEACHER'S VISUAL ATTENTION WHEN SCAFFOLDING SMALL-GROUP PROBLEM SOLVING

Study I started from the perspective that scaffolding interaction between teacher and students is essential for beneficial learning in collaborative problem solving. This perspective was also central in our research project, one of its objectives being to explore teacher activities that facilitate student collaboration. This case study examined what kind of visual information the teacher collects during this interaction. The results indicated that different scaffolding intentions require different kinds of visual attention, because certain targets contain relevant information for pedagogical in-situ decisions.

The participant teacher, Fred, was a 30-year-old man with three years of experience teaching mathematics. The data analyzed included three types of data: gaze-tracking data from the teacher, classroom video recordings of his mathematics lesson, and the stimulated recall interview with the teacher after the lesson. The gaze data was annotated by dwells and synchronized with stationary classroom video recordings. The classroom video served as a source of qualitative coding of the scaffolding intentions. From the video, I selected the teacher's scaffolding events with the student collaboration groups and divided the teacher's interaction into five categories of scaffolding intentions: cognitive, affective, and metacognitive scaffolding, monitoring, and fading. The teacher's reflections during the stimulated recall interview helped to ensure the validity of this qualitative coding. The teacher's gaze dwells provide information about the targets and durations of the teacher's visual attention. In the results, the occurrences and durations of the dwells are discussed together as teacher's visual attention, referring to the total dwell time towards the targets. I used descriptive statistics to build an overview of teacher visual attention, Chi-square test to compare the occurrences of the dwells during the scaffolding intentions, and ANOVA to examine the effect of the scaffolding intentions on the durations of the dwells.

The overview of the teacher's visual attention during scaffolding interaction with the student collaboration groups showed that the student-related gaze targets formed three main categories. First, the students' papers and faces are targets on which dwells (papers n = 394, faces n = 239) were relatively long on average (papers M = .71 s, SD = 1.198, faces M = .54 s, SD = .606). These two targets formed the majority of the teachers' visual attention during the collaborative phase of the lesson. The second category of targets was the students' desk, belongings, hands, and bodies. These targets were looked at often (desks and belongings n = 364, hands and bodies n = 342) but with short gazes (desks and belongings M = .28 s, SD = .243, hands and bodies M = .32 s, SD = .371). The third category of targets was at student gestures. I used the gaze code "gesture," when a student pointed at a solution on their working paper with their hand or finger, and the teacher's gaze followed this hand or finger. These gestures occurred often during cognitive scaffolding, when the students explained their thinking while pointing at solutions on their working papers. Gazes coded as gesture occurred only 47 times during the collaborative phase, but their mean duration was the second longest after the paper-targeted gazes with high standard deviation indicating some very long gazes at student gestures (M = .66 s, SD = .904).

The locus of the visual attention of the teacher in this case study varied between the scaffolding intentions. During cognitive scaffolding, the most attended gaze target was the working papers (χ^2 (16, N) = 92.60, p < .001). The paper-targeted gazes were also the longest gaze category with statistical significance (F (4, 389) = 16.43, p < .001). During this scaffolding intention, the teacher also paid attention to the students' gestures more than during other scaffolding intentions. During cognitive scaffolding, the face-targeted gazes were fewer but longer and this difference had statistical significance, than face-targeted gazes during other scaffolding intentions. Students' bodies and desks were looked at less than during other scaffolding categories.

The teacher focused on students' faces more often when scaffolding affective aspects of the collaborative problem-solving process than during other scaffolding categories. The durations of the face-targeted gazes were significantly longer during affective and cognitive scaffolding than during monitoring. Students' hands and bodies, however, were a common gaze target during metacognitive scaffolding as well as the monitoring and fading phases. These gazes were short throughout the collaborative phase.

In this study, I analyzed four scaffolding events qualitatively. The first event represented cognitive scaffolding. During this event, the teacher helped a group of students in confirming their solution and correcting a minor miscalculation. This student group expressed momentary engagement with the task but had difficulties in collaborating. The qualitative analysis of the interaction on this event showed that the teacher narrowed his visual attention to student papers, gestures, and faces while expressing enthusiasm and having fruitful interaction with the students during cognitive scaffolding. These gazes

were also very long, as the teacher focused on understanding the thinking process of the student group.

The two events on affective scaffolding included expressions of negative emotions. One event included interaction between the teacher and a group of four boys, who were joking about the task and even about the teacher. In the second affective event, the teacher tried to encourage an unmotivated and bored pair of girls to work on the task. The teacher's gaze durations decreased during affective scaffolding, when the students expressed negative emotions and the teacher experienced confusion about his pedagogical in-situ decisions. During both of these events of affective scaffolding, the teacher paid attention to the student faces and hands to obtain information about their emotional and motivational state.

In the metacognitive scaffolding event, the teacher's intention was to direct the students' attention towards each other so that they would work collaboratively on the task. This student group was not keen to collaborate or work on the task. Hence, the students avoided interaction and averted their faces away from the teacher. Thus, the teacher had to try to obtain information about the group's problem-solving process by looking at the students' backs, hands, and belongings. By looking at these targets, the teacher was able to interpret the collaboration situation in the group, for example by observing whether a student was holding a pen or a phone in their hand. These targets did not require deep processing to interpret and the gazes at them remained quite short.

6.2 STUDY II: TEACHER-STUDENT EYE CONTACTS IN RELATION TO TEACHERS' SCAFFOLDING INTENTIONS

After Study I, the face-targeted gazes captured my interest. Study I as well as previous research (e.g. McIntyre, 2016) had shown that student faces form one of the two most important gaze targets for teachers in classrooms. The aim of Study II was to investigate teacher gazes at students' faces and the students' responses to them. The research question consisted of two goals. The first goal was to chart the general characteristics of the teacher-student eye contact communication in the classroom and the second goal was to compare the occurrences and durations of the face-targeted gazes between the categories of the scaffolding intentions. Despite the teacher's central role in classroom interaction, I found the students responded with dyadic eye contact only to some of teacher gazes, and started eye contact even less often. The students started eye contact more often if the verbal interaction, that is, the scaffolding intention, invited them to do so.

In the analyses of Studies II and III, data for two female teachers (Joanne and Lily) was included in addition to data from the participant teacher in Study I (Fred). These teachers represent different levels of teaching expertise, which

is the reason why they were selected for this analysis. Study II was purely quantitative. The teachers' gazes upon their students were categorized into three categories: one-sided teacher gaze at a student's face, dyadic student-started eye contact, and dyadic teacher-started eye contact. I analyzed these gazes similarly as in Study I, using descriptive statistics, Chi-square test, and ANOVA.

The overall distributions of the visual attention of the three teachers were quite similar to each other. In the comparison of the gaze proportions (total dwell time) of all three teachers, student papers and displays were the most frequent gaze target (57%), followed by student faces (14%) and bodies and hands (14%). Students' desks and belongings (9%) and gestures (6%) received the least attention.

Closer inspection showed differences in the amount of attention each teacher paid to student faces. Joanne's proportion of face-targeted gazes was lower (13%) than Fred's (17%) or Lily's (19%). Lily's face-targeted gazes were, however, on average shorter than all her other gazes (M = .43 s, SD = .546). This was not the case with Joanne (M = .46 s, SD = .632) or Fred (M = .54 s, SD = .633). In other words, Lily directed numerous short gazes at her students while Joanne and Fred paid more attention overall to student faces but with fewer and longer gazes.

Additionally, the proportion of the dyadic teacher-student eye contacts varied between the teachers. In Joanne's data, 40% of the gazes included dyadic eye contacts, while the percentage was 30% in Fred and 23% in Lily's. However, with all the teachers the students initiated dyadic eye contact (72%) more often than the teachers did. The least frequent type of interaction was eye contact started by the teacher and ended by a student. Fred started dyadic eye contact with his students more often than Joanne and Lily.

Pearson's Chi-square test showed statistically significant differences in the occurrences of the types of face-targeted gazes between scaffolding intentions (χ^2 (8, 379) = 33.47, p < .001). When the teachers monitored the students, the students did not interrupt what they were doing to respond to the teachers' gazes, and dyadic eye contact between students and teachers seldom occurred (16% of the face-directed gazes). During the fading phase, no statistically significant differences in the count of gaze types were found, but the distribution was similar to that of the monitoring phases, namely 14% of the gazes included dyadic eye contact. Probably, despite being directed at student faces, these teachers did not mean these gazes to be initiatives for dyadic eye contact. Rather, these gazes seemed to reflect the teachers' authority role in the classroom while monitoring their students' problem-solving processes and collaboration. The metacognitive scaffolding was relatively similar to monitoring and fading with less dyadic eye contact (32%) than the expected count assumed. During metacognitive scaffolding, the teachers often gave instructions to the students regarding their position and face direction, and then supervised when the students changed seats or positions. Teacher-started

dyadic eye contacts were very few during cognitive scaffolding, monitoring, and fading.

In contrast, dyadic eye contact was more common during cognitive (49%) and affective scaffolding (40%). During cognitive scaffolding, the students were more likely to initiate dyadic teacher-student eye contact. Study I showed that during cognitive scaffolding the teacher paid attention to the students' papers. It seems that the students nevertheless sought information from the teachers' face, and the teachers responded to these initiatives. The face-targeted gazes during cognitive scaffolding were also longer than the gazes during metacognitive scaffolding with statistical significance ($F(4, 370) = 8.45, p < .001$).

The differences in the proportions of interaction used for cognitive scaffolding is probably at least one explanation for the between-individual variation in the amount of dyadic eye contact. Joanne had more dyadic eye contact with students than Fred and Lily, and her scaffolding interaction was also more focused on the cognitive aspects of problem solving. Her students were motivated to succeed in solving the task, and the scaffolding interaction often concerned mathematical topics.

Teacher-started dyadic eye contacts were most common during affective scaffolding. According to Study I, the teacher looked at student faces most during affective scaffolding. This study shows that these gazes represented reciprocal nonverbal communication as a part of the scaffolding interaction. Additionally, the teacher gazes at student faces were significantly longer during cognitive and affective scaffolding than during monitoring and fading.

These results indicate that, during cognitive and affective scaffolding, the teachers' nonverbal communication with students is reciprocal. It is also more peaceful and concentrated than during monitoring and metacognitive scaffolding. During the monitoring and fading phases, the teachers charted the progress of the problem-solving processes in the groups, and their visual attention wandered from target to target among several targets. The clear cognitive or affective intention in the scaffolding interaction seems to focus teacher attention on the relevant targets, and more intense processing of the information on student faces, as is shown by the longer gaze durations. During monitoring and metacognitive scaffolding, the face-targeted gazes were rather like glances that served as one building block in creating a holistic picture of the students' problem-solving process.

Another aim of this study was to identify who initiates reciprocal nonverbal communication (i.e. eye contact) during scaffolding interaction. During cognitive and affective scaffolding, both teachers and students often initiated dyadic eye contact. During cognitive scaffolding, the students took the initiative to make eye contact with their teacher also when the teacher looked at the students' solution papers. For the students, the scaffolding events may have been significant opportunities to receive attention from the teacher, especially in Fred's and Lily's classes, where the target students did not work very effectively on the task. The teachers often responded to the students' eye

contact initiatives during cognitive scaffolding, probably to enhance the scaffolding interaction. During affective scaffolding, the teachers encouraged and persuaded the students who were exhausted, frustrated, or uncertain about the problem task and combined dyadic eye contact gazes with verbal interaction. In these moments, the teachers were often the initiating party for dyadic eye contacts.

6.3 STUDY III: TEACHER-STUDENT EYE CONTACTS IN RELATION TO THE TEACHER'S INTERPERSONAL BEHAVIOR

After Study II, it felt necessary to add the student gazes toward teacher faces into the analysis. In Study III, the same data as in Study II, the three teachers and their gazes at student faces, were complemented with one-sided student gazes at teacher faces and analyzed through the theory of interpersonal behavior. The aim was to examine the relation between gaze interaction and teachers' momentary interpersonal behavior (acts of teacher agency and communion). The statistical analyses included ANOVA on the effect of teacher interpersonal behaviors on the occurrences of face-targeted gazes and Pearson's correlation between teacher interpersonal behaviors and the gaze durations. Additionally, qualitative descriptions on typical moments of nonverbal communication were included in the report.

The most common gaze type in the analysis was teacher gazes at student faces (n = 677), followed by student gazes at teacher faces (n = 512), student-started dyadic eye contacts (n = 298), and teacher-started dyadic eye contacts (n = 175). To summarize the main findings of the study, the students looked at their teachers more often and with longer gazes when the teacher's agency was low and communion was high, because certain teacher interpersonal behaviors invited them to reciprocal interaction.

According to the continuous joystick coding on their interpersonal behaviors, the teachers' behaviors varied mainly among the positive levels of agency and communion. Joanne and Lily represented leading, helping, and a strict teacher character. Joanne had the highest mean scores on both agency and communion. Lily had some passive moments when she retreated from the teacher-student interaction. Fred was more dissatisfied and admonishing, but also, according to our observations, more understanding with his students. Due to the students' lack of engagement, Fred's coding yielded more negative scores of communion than Joanne's or Lily's.

Additionally, the students differed between the classes. Joanne's students were mathematically capable, obedient, and the classroom climate was friendly throughout the lesson. Lily's students struggled with the problem task, but the climate was happy, and Lily seemed to have a high level of authority in her class. Fred's students were the most disobedient and the least engaged. While some of his students were highly motivated to solve the problem, the

target students were more interested in social interaction than working persistently on the problem.

The first main finding in Study III was that the student gazes at teacher faces were more frequent ($F(3, 1658) = 16.8$, $p < .001$, $\eta^2 = .029$) and longer ($r(502) = .292$, $p < .001$) during high teacher communion. This was especially evident in Joanne's data. Her level of communion was higher during student gazes at her ($F(3, 476) = 11.3$, $p < .001$, $\eta^2 = .067$) than during teacher gazes upon student faces ($p < .001$), teacher-started eye contacts ($p = .012$), and student-started eye contacts ($p = .005$). Joanne instructed her students with a determined but friendly tone, and the target students often followed these instructions even when Joanne addressed them to some other student.

With teacher agency, the effect on the occurrence of student gazes at teacher faces was the opposite. The students looked at their teachers less often during high teacher agency ($F(3, 1658) = 9.88$, $p < .001$, $\eta^2 = .018$), while the correlation between teacher agency and student gaze durations was slightly positive ($r(502) = .142$, $p = .001$). However, this finding was not uniform among the teachers. With Lily and Fred, the students looked at their teachers when the teachers conveyed low agency. For instance, in an example excerpt from Lily's data, the students looked at her while they asked her to look at their solution drawings, and she did as they requested. Later, when Lily's agency increased, eye contact was dyadic between her and the student.

In Joanne's lesson, however, the students looked at her often during high teacher agency ($F(3, 476) = 4.70$, $p = .003$, $\eta^2 = .029$), that is, when she gave them instructions. Joanne's teaching style was leading and the students also seemed to wait for instructions from her during the small-group scaffolding ($F(3, 209) = 2.70$, $p = .046$, $\eta^2 = .037$).

Student-started dyadic eye contacts occurred more often during high teacher communion in Lily's and Joanne's lesson but not in Fred's. This was also the case with the durations of the student-started eye contacts and teacher communion. The correlation was negative with Fred ($r(123) = -.267$, $p = .003$), while it was positive with Joanne ($r(129) = .218$, $p = .012$). Fred had to appear strict when giving instructions about behavior to his targets students, and during these moments, dyadic student-started eye contacts occurred between him and the students. The students made eye contact initiatives while listening to Fred's reprimands.

To summarize, the results of this study showed a connection between teachers' interpersonal behavior and reciprocal teacher-student eye-contact interaction. The students tended to look at their teachers when the teachers conveyed high communion. It is noteworthy that this data included the phase of collaborative problem solving in the middle of the lessons. From Joanne's data I gathered that the results we obtained might be different if investigated during whole-class instructions. During small-group scaffolding, the quality of teacher agency seemed to have an effect on students' gaze behavior. Simultaneous high communion and modest agency encouraged students to

engage in reciprocal eye-contact interaction, whereas high communion without agency or vice versa could cause puzzlement in students.

7 DISCUSSION

This dissertation examined teachers' visual attention and reciprocal teacher-student eye contacts in moment-to-moment classroom interaction. The general picture of the findings indicates that certain characteristics are specific to teacher-student interaction due to its unique nature. As the following subsection 7.1 summarizes, both teacher attention and reciprocal eye-contact interaction is relative to momentary pedagogy. After the summary on main findings, this chapter discusses the methodological (7.2), theoretical (7.3), and practical (7.4) implications. Finally, subsection 7.5 presents the concluding remarks of this dissertation.

7.1 MAIN FINDINGS

Here I present the main findings of the studies. First, I summarize the findings on teacher's attentional distribution in the classroom by introducing three categories of the teacher's relevant gaze targets. Secondly, I combine the findings of all three sub-studies and reflect on the relation of teacher-student eye-contact interaction to teachers' momentary scaffolding intentions and interpersonal behaviors.

7.1.1 THREE CATEGORIES OF GAZE TARGETS IN THE CLASSROOM

The gaze targets in the mathematical scaffolding interaction can be divided into three main categories. In the first category, student faces and solution papers were the two most significant targets receiving the highest proportion of teacher attention in terms of both the occurrences and the durations of the gaze dwells. Some targets, such as students' belongings and hands, are targets of gaze dwells that are very frequent and yielded numerous gazes that were short. These targets form the second category. In the comparison of eye contact gaze types, teacher gazes at student faces represented this category. They were very frequent but short. The third category are gaze targets that received few gazes that were, nevertheless, quite long. In the distribution of teacher visual attention, student gestures belonged to this third category. In eye-contact communication comparison, teacher-started dyadic eye contacts, appeared to be few but were long.

The occurrence of the gazes is generally seen to indicate the significance of the target and the duration reflect gives an indication of the complexity of the target (Holmqvist & Andersson, 2017). Hence, I interpret the gaze targets of the three categories to represent distinct intentions of instruction. Student faces and solution papers are without doubt the most relevant targets in the classroom. This has been found in the context of teachers' general whole-class

instructions (McIntyre et al., 2019) and is also aligned with the context of group-level scaffolding as well. These targets include information that is essential for the instruction and which also require pedagogical interpretation, that is, cognitive processing.

Student hands and the objects on their desks are relevant for the teacher as well as for charting student activities. Whether a student is holding a pencil or a phone informs the teacher of their momentary motivation by means of a short glance. Teacher expertise has been found to correlate with the flexibility and purposefulness of the visual attention (Cortina et al., 2015; McIntyre et al., 2017). Short glances at student hands, bodies, and desks indicate that teachers can scan these targets quickly before moving on to more complex attentional tasks (van der Bogert et al., 2014). Short gazes may also relate to the teacher's emotional load. Study I indicated the teacher gazes at student faces shortening during moments of emotional confusion, and Study III showed a statistically significant negative correlation between teacher agency and gaze duration in dyadic eye contact. However, this result surfaced in the analysis of data from Joanne, whose data in this correlation was strong enough to affect the whole data. The stronger agency teachers conveyed, the shorter were their dyadic eye contacts with the students. Thus, short gazes in the classroom result not just from the simplicity of the target but also from the in-situ pedagogical interaction.

With gestures, however, the students convey more complex and deep aspects of the learning process, and the teachers have to focus on interpreting them carefully. Unfortunately, these fruitful moments were quite few in our data. In Joanne's class, where the scaffolding interaction was more focused on cognitive goals as the students were engaged and well behaved, the student gestures were more frequent and Joanne focused on them carefully. The fact that the teachers clearly paid attention to student gestures, whenever those occurred, indicates that they saw them as significant for beneficial scaffolding interaction. By focusing on the student's gestures reaching the solution (and simultaneous verbal presentation), the teacher can either consciously or unconsciously direct the students' attention toward the learning goals by conveying their pedagogical values and aims (Csibra, 2010; Frith & Frith, 2012).

7.1.2 RECIPROCAL TEACHER-STUDENT EYE CONTACT COMMUNICATION IN THE CLASSROOM

A teacher's visual attention as well as teacher-student eye contacts were reactive to the teacher's scaffolding intentions during teacher interaction with collaboration groups in mathematical problem-solving lessons. During cognitive scaffolding, teachers directed their attention toward the mathematical contents of the students' papers, yet these moments included the highest proportion of student-started eye contacts. It seems that teacher-led interaction concerning the mathematical contents of the learning process

directs student attention toward the teacher's face. Study III indicated that student gazes at teachers were frequent during high teacher communion, that is, friendly teacher behavior. In Joanne's class, the general climate was positive towards learning, and the scaffolding interaction was fruitful: the students posed questions and expressed their emotions, and the teacher was able to convince them to continue working and was able to help them cognitively as well. In Joanne's and Lily's classes, student-started eye contacts occurred during low teacher agency and high communion. Fred's target students were less motivated, and teacher agency occurred during lower communion scores: Fred had to reprimand them. In Fred's data, student-started dyadic eye contacts occurred during high teacher agency and low communion.

During affective scaffolding, the students' faces were in the focus of teacher visual attention. The teachers' gazes often looked at students' faces and these gaze dwells were long in duration. The students also often responded to the teacher eye-contact initiatives, and several teacher-started dyadic eye contacts were formed during affective scaffolding. However, affective scaffolding often included negative student emotions, teacher persuasion, and even conflicts. Among less motivated students, low teacher agency directed student gazes at the teachers' faces. In Joanne and Lily's lessons, teacher-started dyadic eye contacts occurred during relatively high teacher agency and low communion. However, Fred's students opposed him. In Fred's data, high teacher agency and low communion yielded were correlated with both teacher-started and student-started dyadic eye contacts. I interpret this to reflect the general climate in the classroom.

Metacognitive scaffolding as well as monitoring and fading moments at the beginning and end of scaffolding interaction events directed teachers' visual attention toward targets conveying the character of student activities. Study I showed that Fred paid attention to students' hands as well as their belongings while charting the progress of the students' problem-solving process and offering metacognitive scaffolding. In these moments, dyadic eye contacts were very few. The students did not become distracted from their work due to the teacher's gazes at them, and did not look back at the teachers when the teachers instructed them when directing the conversation or attention toward the learning process. The comparison with the teachers' interpersonal behaviors showed that one-sided teacher gazes at students were common during moderate teacher agency and communion. In my studies I did not investigate reasons for gaze aversion, but some interpretations can be obtained based on data triangulation. Probably, the students felt discomfort or discouraged about collaborating, as they were not allowed to choose their collaboration groups, and they conveyed this dissatisfaction by means of gaze aversion. Some students may also have wanted to convey engagement to with the task by focusing on it during teacher monitoring.

Only the last of the three sub-studies included analysis of students' gazes at teachers' faces, and thus cannot be understood in the light of teachers' scaffolding intentions. The relation between these gazes and teacher

communion was probably the clearest individual finding in the statistical analyses in Study III. An ANOVA analysis showed a significant effect on the relation between the occurrence of one-sided student gazes at teachers' faces and teacher communion, communion being higher during these gazes. Additionally, a positive correlation between the durations of these gaze durations and teacher communion existed. Due to the relatively high inter-individual variation, many of the statistical results were tentative, but this one was very clear.

From a teacher's perspective, fruitful teacher-student interpersonal interaction is a combination of leadership and friendliness (den Brok et al., 2002; Yu & Zhu, 2010). However, the findings of the sub-studies show that students can have significant agency in a momentary interaction, as shown in their eye contacts and gaze aversions. Teacher and student roles set expectations for their interaction and interpersonal behaviors. Even though the teacher may seem to lead an interaction with verbal cues and scaffolding, students have the possibility to affect the course of events with subtle nonverbal behaviors, such as gaze aversion or direct gaze at the teacher's face. Momentary student agency may be implemented in delicate subtle nonverbal communication. To capture this, methodological and analytical decisions have to be delicately fine-grained as well.

McIntyre et al. (2019) have claimed that teachers' visual attention in moments of speaking is different to their visual attention when listening to students. The analyses in this dissertation allow me to draw somewhat more fine-grained conclusions. Teachers seem to seek for joint attention and social togetherness during affective scaffolding and for short moments of high teacher agency and low communion. Students, on the other hand, seek for eye contact during cognitive scaffolding and low teacher agency and high communion. I suggest that cognitive (mathematical) scaffolding is what the students are urged to concentrate on during mathematical problem solving, and in these moments they wish for interaction with the teacher, whereas affective scaffolding often takes place when the students are frustrated or unmotivated, and the teacher tries to persuade them to persist with their task. Thus, gaze behavior is formed not merely in the mind of the individuals in the classroom but between them, in their social interaction. Despite its practical challenges, using multiple gaze trackers is necessary for reaching the social aspects that are at the very heart of education.

7.2 LIMITATIONS AND IMPLICATIONS OF METHODOLOGY

As this research represents relatively novel approaches to educational research on the one hand, and to eye-tracking research on the other, it provides diverse new insights into methodology. In this subsection, I reflect on the limitations of this study and propose methodological implications for preparing data

collection (7.2.1), analyzing gaze data (7.2.2), and utilizing the face-to-face eye-tracking paradigm (Holmqvist & Andersson, 2017) in education (7.2.3). Due to the mixed method approach of this thesis, I combine criteria related to qualitative and quantitative research, as both these components have probably affected each other and the whole thesis (see O'Cathain, 2010).

7.2.1 LIMITATIONS AND REFLECTIONS ON THE RESEARCH SETTING

Many eye-tracking researchers share the idea that optimal gaze data should be collected in naturalistic environments (Hessels, 2020; Shayan et al., 2017; Kredel et al., 2017). However, eye-tracking technology still sets limitations on research settings and forces researchers to choose between external validity (the naturalistic setting) and reliability (the size of the data set) (Kredel et al., 2017). Moreover, multiple mobile gaze tracking is a challenging method to collect data in an educational context. Reviews of educational eye-tracking research have recognized a small sample size, a narrow context, and a laboratory setting as its general limitations (Beach & McConnel, 2019). Due to the complexity of the research setting, our sample size is restricted, and we suffered from some loss of data due to technical issues. Our data came from an authentic environment, but it is true that the sample of this dissertation is small and the learning contexts were similar despite the variance between students' social-economic backgrounds, class sizes, and the teachers' personal characteristics.

Despite the fast development of deep learning on video scene analyses, human vision is still the most efficient tool for analyzing the contents of videos in authentic environments (Abbas, Ibrahim, & Jaffar, 2018). Current technology does not provide sufficient tools for analyzing pedagogical activites, nonverbal behaviors or gaze targets on video data with automatic scene recognition. Thus, the coding and analysis were conducted manually (Jarodzka et al., 2017). The time-consuming nature of analyzing gaze data is nowadays a shared consensus among researchers (Hyrsykari et al., 2008; Beach & McConnel, 2019). Our project team has developed methods for automatic gaze coding based on visual markers set in the environment of the data collection. However, the coding for the studies of this dissertation took place before this methodological work was ready for use. I suggest that by using a restricted amount of data and standardizing as many variables as possible in the data collection context, the researcher is able to focus on reflecting about the interaction between the participants and its relation to the educational events. Additionally, the periods of data collection were few but rather long and included more than an adequate amount of interaction for valid analytical interpretations. The small number of participants allowed adding micro-level within-individual interpretations into the analysis.

Classrooms with collaborative learning are a special setting for collecting data. The setting up of video cameras and microphones succeeded quite well, and all the discussion of the target student groups was audible in the

recording. Having said that, placing more microphones around the room would have improved the dependability of this research by offering richer data, including an analysis of the conversations of other student groups as well. The qualitative descriptions on these scaffolding events in Study I were based on a personal microphone worn by the teacher, which functioned quite well when the teacher scaffolded the group. However, this is an aspect to keep in mind when interpreting the results. The studies of this dissertation focused on the teacher perspective of scaffolding interaction. To be better aware of the student perspective, student conversations before and after the teacher-student interaction should be added to the analysis.

The validity of gaze recordings relies on the accuracy of the device. The research group endeavored to calibrate the mobile gaze trackers carefully. The data indicated that the calibration was successful, and the calibration maintained its accuracy even if the participant took the glasses off for a moment during the lesson. The circle marking the gaze direction was usually located in a way that was aligned with the eye-mind assumption, e.g., the teachers focused on the target they were speaking of. Sometimes, when the gaze target was situated far from the research subject and the objects in the environment were smaller in the video, it was less clear what the target was. Fortunately, this had little effect on my research, as I examined the group-level scaffolding interaction events when the teachers stood by the students who were in the locus of their attention and vice versa, and when the target of the gaze was quite clear. Here the methodological concepts of validity and credibility complement each other. In this mixed method thesis, manual coding was assisted by both accurate equipment and the multimodal data set (gaze, visual, audio). Conducting reliable research on gaze behavior requires functioning equipment. The robustness of the gaze trackers was a strong point in our project. Using less accurate devices for such fine-grained analyses would probably have been not only unreliable, but even impossible.

7.2.2 LIMITATIONS AND REFLECTIONS ON THE ANALYSES

In addition to the accuracy of the devices, manual coding affects the validity of the measurements. Most of the time, the gaze target was unambiguously clear when I coded the gazes of teachers and students. This results from scoping the coding in the light of the research questions. The research questions directed the gaze coding. As the teacher's interaction with scaffolding groups was the research topic, research equipment or other gaze targets located far from the teacher did not require accurate coding. However, sometimes the gaze targets were difficult to interpret. For example, many students used transparent rulers or had pencils or headphones on their solution papers, and there were moments when the teacher seemed to gaze at the paper "through" these transparent or very narrow objects. In these situations, I interpreted the gaze targetss based on the verbal interaction and the attentional context, relying on

the eye-mind assumption. Additionally, these gazes were so rare that even miscoding them would have affected the quantitative results only marginally.

The varying sizes of the gaze targets, or areas of interest, as often referred to, may affect the reliability of gaze tracking studies. Areas of interest are always researcher-defined, and these methodological decisions can vastly affect the results (Holmqvist & Andersson, 2017). Generally speaking, with static eye trackers, the larger the area of interest is, the more gazes are directed toward it (Strohmaier, 2020), and researchers have to take this into account when interpreting the results. When analyzing our data we did not have this problem. The blackboards were the largest area of interest, but only very few teacher gazes were directed toward it, even when the teachers stood by the student group facing the front of the class.

Rather than the gaze targets, the gaze durations were sometimes difficult to determine. As this research did not aim at charting the cognitive or perceptual processes of the participants, but the visual attention, I had decided not to code saccades and to focus on the dwells on gaze targets instead. Thus, I may say that the coding was comprehensive from a pedagogical viewpoint: all the gazes during scaffolding interaction were included in the coding, but were not comprehensive from the psychological viewpoint: saccades were not included in the reflection on gaze behavior. The video showing the target in the environment showed twenty-five frames per second, that is, a picture of the situationevery 40th millisecond. Sometimes the gaze target changed during the 39 milliseconds that are not visible to the researcher. For example, one-frame-long eye movement fixations outside the determined area of interest were not considered to start a new dwell in my coding, if the gaze continued on the same target immediately after these brief excursions of the eye. This example illustrates the idea of excluding the saccades from the analysis. If the gaze types had been in the locus of the research, these kinds of saccades away from the target and back again would have been an essential part of the analysis (e.g. Hanley, 2015; McIntyre, 2016). However, previous research has concluded that most of the teachers' visual attention is driven by top-down processes (McIntyre & Foulsham, 2018), and I wanted to analyze the intentional, pedagogical vision of the participants. Fixations of one frame are too short to include in intentional perceptional information for pedagogical decision-making (Galley et al., 2015; Holmqvist & Andersson, 2017).

7.2.3 METHODOLOGICAL IMPLICATIONS FOR EYE-TRACKING RESEARCH IN EDUCATION

Our data differs in nature from the body of eye-tracking research conducted in laboratory settings. Collecting data in an authentic social environment guided by educational research questions has an impact on the data. What we lost in generalizability due to our partially standardized research setting, we gained in the reliability and transferability of the findings (see Jarodzka et al., 2017).

In authentic classrooms, the size of the room, the light conditions, and many other aspects may affect the participants' gaze behavior. For example, we are unable to interpret the emotions of the participants by analyzing the differences in the size of the pupil, as the light conditions vary when the participants move around the classroom. Instead, we can make interpretations on their emotions from their verbal and nonverbal interaction. And, what is most significant, we can rely on our findings to represent authentic classroom interaction. Eye-tracking researchers in education share the consensus that conducting the study in a laboratory limits the generalizability of the results (Beach & McConnel, 2019; Tatler et al., 2011). Our data consist of real-life mathematics lessons in a natural social and physical environment. Research always includes choices and emphases that affect the data. Our choice has been to try to understand the contextual social phenomenona in instruction and to map out new aspects of teacher-student interaction, rather than validate general patterns with large samples.

This dissertation adopts the paradigm of analyzing classroom interactions with continuous coding. I used continuous coding both to make sense of the classroom stationary videos of teacher-student interactions and activities, and for teachers' and students' gaze data. I coded the gaze targets and teachers' scaffolding intentions with ELAN software and the teachers' interpersonal behaviors using the CAID method. Hence, all the data in the quantitative comparisons were situational in nature. This affected the interpretations of the results. First, certain general tendencies were found in the data. It was clear that teachers' scaffolding intentions were related to distinctive teacher visual attention and teacher-student eye-contact communication. The results on the teachers' interpersonal behaviors and teacher-student eye-contact communication were somewhat more complex, but some basic principles were also present there. Thus, I may conclude that continuous coding is a useful tool for charting the teacher's gaze behavior.

However, the results should be interpreted in the light of their momentary nature. This dissertation consists of three case studies on three Finnish mathematics teachers and lessons. The generalizability of the results is thus very limited. This should not be seen as a flaw in this research but rather as a feature of its approach. The situational micro-level of classroom interaction is now a little less foreign to the educational research community.

In addition to the momentarity and multimodality of the data and analyses of this research, it has aimed at understanding the social entity of instruction. Previous eye-tracking research has mainly been conducted with one individual wearing a tracker. In Study III, I combine simultaneous data from the teachers and three to four students. Hence, the interpretations of these findings can go further than the eye-mind assumption or the teacher's visual attention. We can examine the space between individuals. In the results and discussion, I have aimed to reflect on what kind of social interaction in the instructional events led to the gaze behaviors captured by the gaze trackers we observed.

7.3 THEORETICAL IMPLICATIONS

The studies in this dissertation examined the process nature of teacher-student nonverbal interaction in the context of mathematical problem solving. In this subsection, I reflect on the continuous nature of the data and the findings of this dissertation from the perspective of existing research literature and theories. Teacher attention is directed by top-down processes and by their intentions and pedagogical knowledge (McIntyre & Foulsham, 2018). The teacher both provides and collects information through gaze (Frischen et al., 2007; Gobel et al., 2015; McIntyre, 2016), and the gaze becomes a social construct in the interaction with the students (Goodwin, 2017). Thus, the teacher's gaze is always part of reciprocal teacher-student interaction in the classroom.

The relation between the static and in-situ factors of instruction or teacher and student affective states and traits (see Hannula, 2012) is an ongoing discourse that has lately expanded through the development of methodology. Computational learning and artificial intelligence in analyses as well as physiological measurements such as eye tracking have enabled scoping into micro-level phenomena in the classroom. Often, the continuous-measurement data is compared to data on rather static aspects, such as a teacher's interpersonal style (Pennings et al., 2018), cultural background, or expertise (e.g. McIntyre et al., 2019). This dissertation, however, compares teachers' and students' momentary attentional and communicational patterns with teachers' in-situ pedagogical intentions and interpersonal behaviors. The theoretical insight this approach offers to the research community needs to be carefully reflected upon.

7.3.1 GAZE BEHAVIOR AS A PART OF CLASSROOM RELATIONSHIPS

Pennings et al. (2018) have stated that micro-level classroom interaction behaviors are the building blocks of teacher-student relationships, which, as we well know, have significant impact on a teacher's professional development (Rojas-Drummond & Mercer, 2003), on students' wellbeing (Esmonde, 2009; Roseth et al. 2008), and on learning (Ellis, 2000). The following two examples illustrate the relation of the static and momentary components of teacher-student interaction. First, in Fred's interview (Study I), he reflected about his pedagogical decisions in the light of his larger pedagogical vision. However, the interview also revealed how much the situational aspects, such as the time of the data collection lesson, affected the interaction in the classroom and the implementation of his pedagogy. Further, these situational implementations of the teacher's pedagogical vision were visible in the gaze data. For example, the data collection took place at the end of the students' last year in comprehensive school, and the atmosphere in the lesson was not very goal oriented. This affected the students' behavior, which in turn affected Fred's

gaze durations and distribution. The purpose of reflecting on these circumstances is to point out the importance of using background theories in a way that enables interpretations concerning the momentary interaction. Examining the micro-level of classroom interaction opens up new perspectives to teacher-student relationships and can confirm us on the situational nature of educational knowledge.

Second, momentary interpersonal behaviors are related to teacher interpersonal style (e.g. Pennings et al., 2018). This research showed the connection between gaze behavior and the teacher's interpersonal behavior. Theoretically, we may assume that teachers' gaze behavior is, in its conscious component, one sort of implementation of a teachers' interpersonal style. Eye contact is part of nonverbal communication, and thus it was expected that some kind of relation between the teachers' gaze behavior and their holistic interpersonal behaviors was to be found. However, the students' eye-contact communication was also found to be relative to the teachers' interpersonal behaviors. This finding adds to the discussion about the reciprocity of teacher-student communication: interpersonal adaptation (Pennings et al., 2018) in classroom interaction is also visible in micro-level nonverbal communications. Hessels (2020) has proposed that the interpersonal context surrounds a face-to-face gaze interaction, and the aim of the interaction affects the individual interactors. In this dissertation, I suggest that both these aspects also occur on a social level between the participants, as they become visible when reciprocity is added to the analysis.

Using the metaphor of the building blocks of teacher-student relationships is useful and convenient. But what actually are those blocks? One block appeared to be gaze behavior. This block is too complex to be comprehensively examined in a single dissertation, but we have seen what part this reciprocal interaction plays in instruction. Additionally, this relation is evident at a conscious and an unconscious level. Students and teachers direct their attention consciously, and may, for example, intentionally look away from dyadic eye contact. However, gaze durations, for example, are to a large extent unconscious (Galley et al., 2015; Tatler et al., 2014).

7.3.2 GAZE BEHAVIOR AS A PART OF PEDAGOGY

The body of recent eye-tracking research has compared teachers' gaze patterns to teacher expertise (e.g. McIntyre et al., 2019; Pouta et al., 2020). The participant teachers in my studies represented different levels of expertise, Fred being quite novice, Joanne in the middle of her career, and Lily quite experienced. Joanne and Fred's data appeared to be more similar than Lily's. However, I am inclined to interpret that the cross-individual variation resulted mainly from the situational differences in lessons, as the results were not clearly in line with previous findings about the effect of teacher expertise on teacher gaze.

For example, Lily had fewer students than Fred and Joanne, and her students had more difficulties in focusing on the task. Lily's students broke off from their work several times during the lesson in order to socialize, and the interaction in Lily's class was very light-hearted and informal. In her lesson, the students were allowed to use laptop computers to solve the problem, whereas Joanne's and Fred's students used only pencils, papers, rulers, and calculators. All these situational factors no doubt affected Lily's gaze behavior. Lily looked at her students during instructive moments of high teacher agency and low communion, and her students looked at her during humorous moments of low teacher agency and high communion, and she often responded to these gaze initiatives. Lily's gazes at her students' faces were shorter than her gazes at other targets. This finding is contrary to previous studies, which indicate longer fixations at students among expert teachers (McIntyre et al., 2017).

Thus, Lily's short gaze durations might indicate a higher in-situ working load (Schulz et al., 2010) while scaffolding the struggling students and taking care of malfunctioning laptop computers, or familiarity with the gaze targets while looking at the students' faces (Holmqvist & Andersson, 2017). Van der Bogert et al. (2014) suggest that short gazes imply either an ability to share the attention between numerous students or inattention to classroom events. In our case, the explanation cannot be the number of the students, as Lily's class had only half the number of students that Joanne and Fred had. Instead, taking care of the learning materials and acting in an emotionally loaded atmosphere were visible in her gaze behavior, contrary to what her expertise would otherwise indicate. Hence, expertise may not be evident in the fixated patterns of gaze behavior, but in the flexibility of attentional processes in relation to changing pedagogical situations. Perhaps Lily was "a novice" in using electronic tools to teach geometry, while Fred and Joanne were "experts" in scaffolding collaborative learning with pencils and notebooks.

7.3.3 THEORETICAL RELATIONS FROM AN ATTENTIONAL PERSPECTIVE

In this dissertation I used two background theories: scaffolding intentions and Interpersonal Theory. Both reflected a situational perspective, not the viewpoint of the intentions of mathematical problem solving in general or of teachers' personal traits. Scaffolding is a professional activity of teachers where they implement their pedagogical views as well as the curricular goals of instruction. Thus, scaffolding theory can be seen to answer the question *why* teachers act the way they do (see Figure 2 on page 34). Interpersonal Theory, on the other hand, deals with a person's manners and patterns of verbal and nonverbal actions in relation to other people, and answers the question *how* do teachers behave in order to reach their pedagogical goals. We can examine the findings in this dissertation from this angle as well.

The first two sub-studies showed the distribution of teacher attention and provided insight as to *why* teachers focus on certain targets at certain moments. The teachers' momentary intentions were visible in their attention. Gaze behaviors were distinct during cognitive, affective, and metacognitive scaffolding. The third study explored *how* teachers implement their pedagogy in action and what kind of role the gaze plays in that implementation. The teachers' interpersonal behaviors, that is, the levels of communion and agency, varied within their scaffolding interactions. Teacher attention was partly related to their interpersonal behavior, but student gaze at the teacher was in clear relation to the teacher's communion and agency behavior. Students looked at teachers more often and with longer gazes during high teacher communion. Teacher agency was low when students looked at teachers' faces (Fred and Lily), or in Joanne's case when teacher agency was high. In Joanne's data, there was also a significant positive correlation between the durations of student gazes at her face and her agency.

This between-individual variation indicates that the intentional nature of teacher-student interaction implies that it is insufficient to focus merely on concrete situational behaviors. Intentions also need to be taken into consideration. Pennings et al. (2018), for example, found that teacher-student interpersonal adaptation varied with regard to momentary leadership across the changes of the levels of communion and agency. Probably, this variation needs to be explained pedagogically rather than behaviorally. Teacher and student behaviors seem to differ in response to instructional circumstances, and this is also evident at the micro-level of nonverbal interaction. I conclude that both psychological and educational perspectives are needed for a comprehensive understanding of teachers' and students' visual attention and eye-contact interaction.

Interpersonal Theory, originally developed for interaction between equal peers (Leary, 1957), is also known to be valid for instructional contexts (e.g. Brekelmans et al., 1990; Pennings et al., 2018). However, teachers' behaviors are not just reactions to stimuli, and the teacher's gaze is not purely directed by the general laws of perceptual psychology (McIntryre & Foulsham, 2018). This dissertation provided novel evidence indicating that neither is student gaze in teacher-student interaction. The teachers' situational implementation of social status affected students' tendency to either join dyadic eye contact or avoid it.

The relation between scaffolding theory and Interpersonal Theory would serve as an interesting topic of research in the future. This could be explored through three viewpoints: affective, cognitive, and nonverbal. First, finding out how teachers' levels of communion vary during moments of affective scaffolding, and how this affects the teachers' and students' eye-contact interaction, would be worth investigating but would also require a dataset which is significantly larger than the one in this research. During affective scaffolding, teachers can either intentionally seek shared immediacy or refuse it through disciplinary actions. The nature of teachers' and students' gaze

before, during and after these kind of behaviors of either high or low communion could provide new insight into the nonverbal and somewhat unconscious parts of instructional interaction.

Second, if we compare the results of Studies I and II to previous research, we could conclude that teachers' cognitive load decreases during moments of cognitive scaffolding (cf. Prieto et al., 2015). The teachers were found to respond to the students' gaze initiatives and gestural cues during cognitive scaffolding. When the teacher seems to have the leading role (high agency) in the moment, the student initiatives may be very subtle but still meaningful for the scaffolding interaction. Student-started joint attention has been found to benefit the learning process (Kim & Mundy, 2012) and experiences of communion (Grynszpan, Martin, & Fossati, 2017) more than teacher-started joint attention. In Study III, the student-started eye contacts were in connection with low teacher agency. In the future, we could explore whether teacher agency or the way students perceive it is lower during cognitive scaffolding. Do the students feel safe when the scaffolding is about mathematical contents rather than their engagement or group work? Is conveying situational agency easier for teachers during cognintive scaffolding than during affective scaffolding?

The third aspect about the relation between teachers' interpersonal behaviors and scaffolding intentions is the significance of the moments of nonverbal monitoring and fading. These moments did not include verbal scaffolding, but were clearly visible in the data and were supported by scaffolding theory (van de Pol et al., 2010). The transfer of responsibility from the tutor to the learner is an essential part of beneficial scaffolding interaction (Stone, 1998), and is implemented during the fading phase of the scaffolding intervention immediately before the teacher moves on to the next student group. In interpersonal behaviors, this could be seen as diminishing momentary teacher agency: the teacher is not speaking or acting explicitly, but scanning student faces, body positions, and their belongings rather than the solution papers. Hence, despite the lack of explicit agency, teacher authority may be especially concrete in these moments. The students probably acknowledged the attention they got from the teacher and may have interpreted it from their own perspective and adapted their actions in ways they assumed the teacher preferred (cf. Böckler et al., 2016). How teachers' attentional presence affects student behaviors and attention is supposedly relative to the teacher-student relationship. Investigating this connection might reveal something significant about the relation of the momentary micro-level processes and static macro-level relationships in classrooms.

7.4 PRACTICAL IMPLICATIONS

This dissertation is based on three studies that examined teacher-student interactions from a novel perspective, and hence were descriptive rather than

confirmatory or normative. Drawing direct implications from such basic research for classroom practices is not simple. Nevertheless, I wish to raise two important aspects of classroom interactions for consideration. First, I suggest teacher professional development could benefit from teachers thinking about their gaze behavior and student responses to it (7.4.1). Secondly, I wish to underline the importance of seeking joint attention in collaborative learning (7.4.2).

7.4.1 PROFESSIONAL LEARNING THROUGH REFLECTING ON GAZE BEHAVIOR

Mobile gaze tracking offers novel possibilities for professional development. The stimulated recall interviews taught us that reflecting about one's own visual perceptions is not an easy task. Nevertheless, we could set a well-planned situation for teachers to follow their own gaze behavior by watching the gaze recording and reflecting about the interactional aspects. This could serve as a beneficial tool for enhancing their understanding of their own pedagogical behaviors and intentions and student responses to them.

For instance, gaze aversion seemed to play an important role in teacher-student nonverbal interaction. One-sided face-targeted gazes were significantly more frequent than dyadic eye contacts. Also, dyadic eye contacts were more often started by the students than by the teachers. In this study, students tended to look at their teachers less often and with shorter gazes when the teachers conveyed low communion. Similarly, the students did not respond to teachers' gazes at their face during monitoring and fading phases and metacognitive scaffolding as often as during cognitive scaffolding. While psychological research agrees about the effect of sudden face-targeted gazes as cues to nonverbal interaction (Böckler et al., 2014), not responding to gaze cues was common in our data. Probably a teacher's direct gaze is not sudden to students, but is expected, and thus tolerated, during teacher scaffolding. If a teacher looked at students in another context, such as during the lunch break, the teacher's gaze might be experienced differently and thus might have elicited a response from the students. In addition, the teachers may avoid looking at students when they do not have possibilities to provide sufficient scaffolding due to, for instance, lack of time. However, student nonverbal responsiveness is known to affect teachers' self-efficacy, liking of the students, and teaching motivation (Mottet et al., 2016). Hence, it would be important to reflect on these aspects in the context of professional learning and investigate them in mixed method eye-tracking studies in the future.

In addition to nonverbal gaze interaction, professional learning could benefit from reflecting on the teachers' own visual attention. Also, watching someone else's gaze behavior during instruction and thematic reflections on these observations could provide a completely new perspective to teachers. The data indicate that the gaze distribution reflects the teachers' momentary pedagogical intentions and can make the unconscious level of teachers'

pedagogical vision visible to the researchers. Previous research has discussed teachers' proportional attention (e.g. McIntyre et al., 2019) and the gaze distribution between students (e.g. Dessus et al., 2016). The researchers nevertheless disagree on whether the uneven attentional proportion characterizes expert knowledge (Dessus et al., 2016) or an inability to spread the attention in the classroom (Stürmer et al., 2017). In this research, I explored the teacher's gaze at collaboration groups of four students. It was true that the teachers paid attention to misbehaving students but also to those who succeeded in solving the problem task. This pattern was similar in the cases of Fred and Lily, who possessed very different levels of teacher expertise. In Fred's data, we see that Fred instructed a pair of students who had succeeded in solving the task to share their thinking with others, but he did not check whether they obeyed, but instead moved on to check upon other student groups.

Although students, and especially teachers, generally prefer behaviors of relatively high teacher agency (and communion) in classroom instruction (den Brok et al., 2002; Mottet et al., 2008; Yu & Zhu, 2011), students looked at their teacher more often and with longer gazes when agency was low and communion was high. Previous knowledge about student perceptions of teacher interpersonal behaviors is based on student responses to Teacher Interaction Questionnaires, which means that they represent a rather static conception of the issue. The studies cited above also concern instruction in general. In our data, the lessons consist of collaborative problem solving, a method of instruction that includes much student agency relative to teacher agency. Hence, it is notable that agency in this study was both interactional and situational. The implementation and need of teacher agency and communion in nonverbal communication in different instructional and interactional situations could provide substance for teachers' professional development.

Many students wish for teachers who convey high communion (den Brok et al., 2002). This research has shown us that this conception is also visible in the nonverbal communication of students. Future research with a larger sample could seek to confirm if students have micro-level agency in directing the teacher towards preferred interpersonal behaviors by responding to the behaviors that support the preferred style and ignoring those that do not. For example, student responses to the teacher's gaze cues during high teacher communion might lead teachers to convey more immediacy in their instruction.

7.4.2 AIMING TOWARDS JOINT ATTENTION

The teacher's gaze distribution among other targets was also related to their pedagogical intentions. During scaffolding interaction, the teacher's attention was mostly targeted at students' solution papers. This was especially evident during cognitive scaffolding when the intention of the instruction was

mathematical. The solution papers were looked at frequently with gazes that were longer in duration than gazes at other targets. Study II showed that during cognitive scaffolding students looked at their teachers more than the teachers looked back at them. This indicates that while the teacher's attention was directed at the mathematical information on student papers, the students sought information or guidance from the teacher's face. Joint attention has been found to be beneficial for collaborative learning (Esmonde, 2009; Roseth et al. 2008). The verbal data indicate that a shared understanding of the intention of situational interaction was often created between teacher and students. However, joint *visual* attention did not necessarily arise between the teacher and students. Analyzing the sequences of teachers' and students' gaze in these situations could provide information on whether joint visual attention also arises during the events of scaffolding interaction. The data showed that not every scaffolding interaction event led to successful progress in the problem-solving process. Students sometimes did not pay attention to relevant targets, resulting from momentary interpersonal behaviors and changes in emotional states. In the future, we could explore what kind of information students seek when they look at a teacher's face in these moments. The teacher's facial expressions and gestures may show whether they are happy with the students' solutions and the progress of the collaboration.

These micro-level findings underline the importance of paying attention to the momentary levels of joint attention in the classroom. Even though humans have a natural ability for joint attention (Böckler et al., 2014) and many teachers acknowledge the importance of eye contact in classroom interaction (Korthagen et al., 2014), harnessing joint attention for beneficial situational teaching intentions is a demanding task. Despite the complex and continuously changing interactional situations in the classroom, the teachers in these studies were able to concentrate on the visual targets that contained relevant information for the momentary teaching goals. By acknowledging and explicating these targets to the students, teachers could direct the students' visual attention as well, and possibly diminish their cognitive load by narrowing their perceptional scope. I suggest future research to explore teachers' embodied cues for directing student attention both for capturing the teachers' unconscious situational expertise and for providing fruitful opportunities for professional learning.

7.5 CONCLUSION

By combining the findings of the sub-studies, I may conclude that, during fruitful interaction of cognitive scaffolding and during teacher behaviors of high communion and agency, the student's gaze tends to focus on the teacher and the teacher's gaze focuses on the learning contents. However, collaborative problem solving is a challenging learning method, and students need affective and metacognitive scaffolding as well.

Affective scaffolding is often connected with negative emotions. The findings indicated that when the momentary interaction was positive towards pursuing the learning goals, and when teachers offered affective scaffolding by looking at their students with an agentic gaze, the students replied to these gaze initiatives, and dyadic eye contact was formed between the teacher and students. However, if the students are willing to challenge the teacher's momentary pedagogy or agency, they can do it with gaze initiative. Previous research indicates that both teachers and students expect and prefer simultaneous high teacher communion and agency (den Brok et al., 2002; Yu & Zhu, 2010). Probably, during moments that do not reflect this expectation, that is, when the teacher is uncertain and admonishing, nonverbal interaction arises that does not obey the general rules and social norms of a classroom. In situations like this, the students made gaze initiatives that were not conducive toward their learning, and possessed high agency through direct face-targeted gazes at teacher.

In metacognitive scaffolding, the teacher aims to direct the student's attention and interaction towards the learning process (Van de Pol et al., 2010). The teacher's visual attention and teacher-student eye-contact communication appeared to be distinctive for this scaffolding intention, resembling moments of teacher monitoring the collaboration groups with no verbal interaction and fading the scaffolding before leaving the group. Why gaze behaviors during metacognitive scaffolding are more similar to gaze behaviors during monitoring and fading than to gaze during cognitive or affective scaffolding remains to be explored in the future. Possibly the teachers' behaviors of agency and communion were moderate during metacognitive scaffolding, but the content of the instructions conveyed their situational authority. Looking at students' body positions and seating arrangement, and giving instructions to change them may possess momentary agency and implicate the social norms in the classroom more than the tone of voice or the nonverbal communication would indicate.

Naturally, behaviors of friendliness are a crucial aspect of teacher-student interaction. We already know that teachers' behaviors of communion increase students' liking of them (Frischen et al., 2007), encourages students to interact (Roberts & Friedman, 2013), and improves students' engagement in learning mathematics (Ellis, 2000; McCluskey, Dwyer, & Sherrod, 2017). Acts of communion also have a significant impact on student attention. In general, if teachers want their students to attend, they should act in a friendly manner during their instructional interaction.

The teachers' gaze is part of their nonverbal interaction and is directed by their pedagogical intentions. Even though scaffolding often occurs at a group or whole-class level, eye contact is always between two individuals, and may illustrate the individual teacher-student relationships that might remain hidden in the interaction of the whole class with other methods. This enables researchers to examine dyadic interpersonal relationships in the classroom context and simultaneously compare them to social-level interactions.

Additionally, this gives teachers a method for reflecting on their pedagogy from the perspective of the individualization of micro-level interactions. Who am I looking at during interaction with student groups and who is looking at me?

The between-individual and even within-individual variation of attentional behaviors underline the relevance of using situational data collection methods and continuous coding. These methods do not need to contradict the use of retrospective verbal or written reflections, but can be complemented by them. In future, developing technologies may provide opportunities for even more fine-grained analyses of classroom interactions. As these results accumulate, they eventually allow summarizing and concluding the results of case studies, hopefully without hiding the situational nature of interactional knowledge. Meanwhile, the contextuality and variance that this kind of research reveals serves us in looking at classroom interactions with new lenses.

REFERENCES

Abbas, Q., Ibrahim, M., & Jaffar, M. (2018). Video scene analysis: an overview and challenges on deep learning algorithms. *Multimedia Tools and Applications, 77*(16), 20415–20453. https://doi.org/10.1007/s11042-017-5438-7

Adams, R.B.Jr., Nelson, A.J., & Purring, K. (2013). Eye behavior. In J. A. Hall & M. L. Knapp (Eds.), *Nonverbal communication* (pp. 229–262). New York, NY: de Gryuter Berlin.

Akechi, H., Senju, A., Uibo, H., Kikuchi, Y., Hasegawa, T., & Hietanen, J.K. (2013). Attention to eye contact in the west and east: Autonomic responses and evaluative ratings. *PLOS ONE, 8*(3). https://doi.org/10.1371/journal.pone.0059312

Alfieri, L., Brooks, P.J., Aldrich, N.J., & Tenenbaum, H.R. (2011). Does discovery-based instruction enhance learning? *Journal of Educational Psychology, 103*(1), 1–18. https://doi.org/10.1037/a0021017

Andersen, J.F., Andersen, P.A., & Jensen, A.D. (1979). The measurement of nonverbal immediacy. *Journal of Applied Communication Research, 7*(2), 153–180. https://doi.org/10.1080/00909887909365204

Anghileri, J. (2006). Scaffolding practices that enhance mathematics learning. *Journal of Mathematics Teacher Education*, *9*(1), 33–52. https://doi.org/10.1007/s10857-006-9005-9

Ausubel, D.P. (1963). *The psychology of meaningful verbal learning*. New York, NY: Grune & Stratton.

Babad, E. (2009). Teaching and nonverbal behavior in the classroom. In L. J. Saha & A. G. Dworkin (Eds.) *International Handbook of Research on Teachers and Teaching* (vol. 21, part 2), pp. 817–828. New York, NY: Springer.

Bakker, A., Smit, J. & Wegerif, R. (2015). Scaffolding and dialogic teaching in mathematics education: Introduction and review. *ZDM Mathematics Education 47*, 1047–1065. https://doi.org/10.1007/s11858-015-0738-8

Barron, B. (2003). When smart groups fail. *The Journal of the Learning Sciences, 12*(3), 307–359. https://doi.org/10.1207/S15327809JLS1203_1

Beach, P. & McConnel, J. (2019). Eye tracking methodology for studying teacher learning: A review of the research. *International Journal of Research & Method in Education, 42*(5), 485–501. https://doi.org/10.1080/1743727X.2018.1496415

Belland B.R. (2014). Scaffolding: Definition, Current Debates, and Future Directions. In: J. Spector, M. Merrill, J. Elen, & M. Bishop (eds.) *Handbook of Research on Educational Communications and Technology*. (pp. 505–518). Springer, New York, NY.

Belland, B.R. (2017). *Instructional Scaffolding in STEM Education: Strategies and Efficacy Evidence*. Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-319-02565-0

Bergman, M. M. (2018). The Century of Migration and the Contribution of Mixed Methods Research. *Journal of Mixed Methods Research, 12*(4), 371–373.

Böckler, A., Eskenazi, T., Sebanz, N., & Rueschemeyer, S.-A. (2016). (How) observed eye-contact modulates gaze following. An fMRI study. *Cognitive*

Neuroscience: Social Attention in Mind and Brain, 7(1–4), 55–66. https://doi.org/10.1080/17588928.2015.1053442

Böckler, A., van der Wel, R.P.R.D., & Welsh, T.N. (2014). Catching Eyes: Effects of Social and Nonsocial Cues on Attention Capture. *Psychological Science, 25*(3), 720–72. https://doi.org/10.1177/0956797613516147

Bolkan, S., Goodboy, A.K., & Myers, S.A. (2017). Conditional processes of effective instructor communication and increases in students' cognitive learning. *Communication Education, 66*(2), 129–147. https://doi.org/10.1080/03634523.2016.1241889

Brekelmans, M., Wubbels, T. & Créton, H. (1990). A study of student perceptions of physics teacher behavior. *Journal of Research in Science Teaching, 27*(4), 335–350. https://doi.org/10.1002/tea.3660270405

Brey, E., & Shutts, K. (2015). Children use nonverbal cues to make inferences about social power. *Child Development, 86*(1), 276–286. https://doi.org/10.1111/cdev.12334

den Brok, P.J., Levy, J., Rodriguez, R. & Wubbels, T., (2002). Perceptions of Asian-American and Hispanic-American teachers and their students on teacher interpersonal communication style. *Teaching and Teacher Education, 18*(4), 447–467. https://doi.org/10.1016/S0742-051X(02)00009-4

Burić I. & Frenzel, A.C. (2020) Teacher emotional labour, instructional strategies, and students' academic engagement: a multilevel analysis. *Teachers and Teaching*. https://doi.org/10.1080/13540602.2020.1740194

Buswell, G.T. (1935). *How people look at pictures*. Chicago, IL: University of Chicago Press.

Cardellino, P., Araneda, C. & García Alvarado, R. (2017). Classroom environments: An experiential analysis of the pupil–teacher visual interaction in Uruguay. *Learning Environment Research, 20,* 417–431. https://doi.org/10.1007/s10984-017-9236-y

Chi, M.T.H. (2006). Two approaches to the study of experts' characteristics. In K.A. Ericsson, N. Charness, P. J. Feltovich, & R. R. Hoffman (Eds.), *The Cambridge handbook of expertise and expert performance* (pp. 21–31). Cambridge, UK: Cambridge University Press.

Claessens, L.C.A., Van Tartwijk, J., Van der Want, A.C., Pennings, H.J.M., Verloop, N., Den Brok, P.J., & Wubbels, T. (2017). Positive teacher-student relationships go beyond the classroom, problematic ones stay inside. *The Journal of Educational Research, 110*, 478–493. https://doi.org/10.1080/00220671.2015.1129595

Cortina, K.S., Miller, K.F., McKenzie, R. and Epstein, A. (2015): Where low and high inference data converge: Validation of CLASS assessment of mathematics instruction using mobile eye tracking with expert and novice teachers. *International Journal of Science and Mathematics Education, 13*(2), 389–403. https://doi.org/10.1007/s10763-014-9610-5

Csibra, G. (2010), Recognizing Communicative Intentions in Infancy. *Mind & Language, 25*, 141–168. https://doi.org/10.1111/j.1468-0017.2009.01384.x

Dalmaso, M., Pavan, G., Castelli, L., & Galfano, G. (2011). Social status gates social attention in humans. *Biology Letters, 8*, 450–452. https://doi.org/10.1098/rsbl.2011.0881

Denzin, N.K. (2012). Triangulation 2.0. *Journal of Mixed Methods Research, 6*(2), 80–88. https://doi.org/10.1177/1558689812437186

Dessus P., Cosnefroy O., Luengo V. (2016) "Keep Your Eyes on 'em all!": A Mobile Eye-Tracking Analysis of Teachers' Sensitivity to Students. In: K. Verbert, M. Sharples, & T. Klobučar (Eds.), *Adaptive and Adaptable Learning. Proceedings of European Conference on Technology Enhanced Learning (EC-TEL 2016). Lecture Notes in Computer Science*. Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-319-45153-4_6

Ding, M., Li, X., Piccolo, D., & Kulm, G. (2007). Teacher interventions in cooperative-learning mathematics classes. *The Journal of Educational Research*, *100*(3), 162–75. https://doi.org/10.3200/JOER.100.3.162-175

Dogusoy-Taylan, B., & Cagiltay, K. (2014). Cognitive analysis of experts' and novices' concept mapping processes: An eye tracking study. *Computers in Human Behavior, 36*, 82–93. https://doi.org/10.1016/j.chb.2014.03.036

Ellis, K. (2000). Perceived teacher confirmation: The development and validation of an instrument and two studies of the relationship to cognitive and affective learning. *Human Communication Research, 26*(2), 264–91. https://doi.org/10.1111/j.1468-2958.2000.tb00758.x

Erikson, E.H. (1964). *Insight and responsibility*. New York, NY: Norton.

Esmonde, I. (2009). Ideas and identities: Supporting equity in cooperative mathematics learning. *Review of Educational Research, 79*(2), 1008–1043. https://doi.org/10.3102/0034654309332562

Frischen, A., Bayliss, A.P., & Tipper, S.P. (2007). Gaze Cueing of Attention: Visual Attention, Social Cognition, and Individual Differences. *Psychological Bulletin, 133*(4), 694–724. https://doi.org/10.1037/0033-2909.133.4.694

Fyfe, E., Rittle-Johnson, B., & DeCaro M. (2012). The effects of feedback during exploratory mathematics problem solving: Prior knowledge matters. *Journal of Educational Psychology, 104*(4), 1094–1108. https://doi.org/10.1037/a0028389

Galley, N., Betz, D., & Biniossek, C. (2015). Fixation durations – why are they so highly variable? In T. Heinen (Ed.), *Advances in Visual Perception Research*. (pp. 83–106) Hauppauge, NY: Nova Science Publishers.

Garcia Moreno-Esteva, E., Kervinen, A., Hannula, M.S., & Uitto, A. (2020). Scanning signatures: A graph theoretical model to represent visual scanning processes and a proof of concept study in biology education. *Education Sciences, 10*(5), 141. https://doi.org/10.3390/educsci10050141

Gaudin, C. & Chaliès, S. (2015). Video viewing in teacher education and professional development: A literature review. *Educational Research Review, 16*, 41–67. https://doi.org/10.1016/j.edurev.2015.06.001

Glöckner, A., & Herbold, A.-K. (2011). An eye-tracking study on information processing in risky decisions: Evidence for compensatory strategies based on automatic processes. *Journal of Behavioral Decision Making, 24*(1), 71–98. https://doi.org/10.1002/bdm.684

Gobel, M.S., Kim, H.S., & Richardson, D.C. (2015). The dual function of social gaze, *Cognition, 136*, 359–364. https://doi.org/10.1016/j.cognition.2014.11.040

Goodwin, C. (2017). *Co-Operative Action (Learning in Doing: Social, Cognitive and Computational Perspectives)*. Cambridge, UK: Cambridge University Press. https://doi.org/10.1017/9781139016735

Grynszpan, O., Martin, J.C., & Fossati, P. (2017). Gaze leading is associated with liking. *Acta Psychologica, 173*, 66–72. https://doi.org/10.1016/j.actpsy.2016.12.006

Guerrero, L. (2017). Conceptualizing and operationalizing nonverbal immediacy. In C. VanLear & D. Canary (Eds.), *Researching interactive*

communication behavior (pp. 61–76). Thousand Oaks, CA: SAGE. https://doi.org/10.4135/9781506349169.n5

Gurtman, M. B. (2009). Exploring personality with the interpersonal circumplex. *Social and Personality Psychology Compass, 3*(4), 601–619. https://doi.org/10.1111/j.1751-9004.2009.00172.x

Hanley, M., Riby, D.M., Carty, C., McAteer, A.M., Kennedy, A. & McPhillips, M. (2015). The use of eye-tracking to explore social difficulties in cognitively able students with autism spectrum disorder: A pilot investigation. *Autism, 19*(7), 868–873. https://doi.org/10.1177/1362361315580767

Hannula, M.S. (2012) Exploring new dimensions of mathematics-related affect: Embodied and social theories. *Research in Mathematics Education, 14*(2), 137–161. https://doi.org/10.1080/14794802.2012.694281

Hannula, M.S., Toivanen, M., & Garcia Moreno-Esteva, E. (2019). Eye movements during collaborative geometry problem solving lesson. In A. Shvarts (Ed.), *Proceedings of the PME and Yandex Russian Conference: Technology and Psychology for Mathematics Education* (pp. 138–145). Moscow, Russia: HSE Publishing House.

Heikonen, L., Pietarinen, J., Pyhältö, K., Toom, A., & Soini, T. (2017). Early career teachers' sense of professional agency in the classroom: Associations with turnover intentions and perceived inadequacy in teacher–student interaction. *Asia-Pacific Journal of Teacher Education, 45*(3), 250–266. https://doi.org/10.1080/1359866X.2016.1169505

Henderson, J.M. (2011). Eye movements and scene perception. In S. Liversedge, I. Gilchrist, & S. Everling (Eds.), *The Oxford Handbook of Eye Movements* (pp. 593–606). Oxford, UK: Oxford University Press.

Hermkes, R., Mach, H., & Minnameier, G. (2018). Interaction-based coding of scaffolding processes. *Learning and Instruction, 54*, 147–155. https://doi.org/10.1016/j.learninstruc.2017.09.003

Hessels, R.S. (2020) How does gaze to faces support face-to-face interaction? A review and perspective. *Psychonomic Bulletin and Review*. https://doi.org/10.3758/s13423-020-01715-w

Hollingworth, A., Schrock, G., & Henderson, J.M. (2001). Change detection in the flicker paradigm: The role of fixation position within the scene. *Memory & Cognition, 29*(2), 296–304. https://doi.org/10.3758/BF03194923

Holmqvist, K., & Andersson, R. (2017). *Eye tracking: A comprehensive guide to methods, paradigms and measures*. Lund, Sweden: Lund Eye-Tracking Research Institute.

Hyrskykari, A., Ovaska, S., Majaranta, P., Räihä, K.-J., & Lehtinen, M. (2008). Gaze Path Stimulation in Retrospective Think-Aloud. *Journal of Eye Movement Research, 2*(4), 118. https://doi.org/10.16910/jemr.2.4.5

Iiskala, T., Vauras, M., Lehtinen, E. & Salonen, P. (2011). Socially Shared Metacognition within Primary School Pupil Dyads' Collaborative Processes. *Learning and Instruction, 21*(3), 379–393.

Jarodzka, H., Holmqvist, K., & Gruber, H. (2017). Eye tracking in Educational Science: Theoretical frameworks and research agendas. *Journal of Eye Movement Research, 10*(1), 1–18. https://doi.org/10.16910/jemr.10.1.3

Jian, Y. & Wu, C., (2015). Using eye tracking to investigate semantic and spatial representations of scientific diagrams during text-diagram integration. *Journal of Science Education and Technology, 24*(1), 43–55. https://doi.org/10.1007/s10956-014-9519-3

Just, M.A., & Carpenter, P.A. (1980). A theory of reading: From eye fixations to comprehension. *Psychological Review, 17*, 329–354. https://doi.org/10.1037/0033-295X.87.4.329

Kabugo, D., Muyinda, P.B., Masagazi, F.M., Mugagga, A.M., Mulumba, M.B. (2016). Tracking students' eye-movements when reading learning objects on mobile phones: A discourse analysis of luganda language teacher-trainees' reflective observations. *Journal of Learning for Development, 3*(1), 51–65. https://files.eric.ed.gov/fulltext/EJ1107314.pdf.

Kendon, A. (1967). Some functions of gaze-direction in social interaction. *Acta Psychologica, 26*, 22–63. https://doi.org/10.1016/0001-6918(67)90005-4

Kiesler, D.J. (1983). The 1982 Interpersonal Circle: A taxonomy for complementarity in human transactions. *Psychological Review, 90*(3), 185–214. https://doi.org/10.1037/0033-295X.90.3.185

Kim K. & Mundy, P. (2012). Joint Attention, Social-Cognition, and Recognition Memory in Adults. *Frontiers in Human Neuroscience, 6*. https://doi.org/10.3389/fnhum.2012.00172

Kojo, A., Laine, A., & Näveri, L. (2018). How did you solve it? – Teachers' approaches to guiding mathematics problem solving. LUMAT: *International Journal on Math, Science and Technology Education*, *6*(1), 22–40. https://doi.org/10.31129/LUMAT.6.1.294

Korthagen, F.A.J., Attema-Noordewier, S., & Zwart, R.C. (2014). Teacher–student contact: Exploring a basic but complicated concept. *Teaching and Teacher Education, 40*, 22–32. https://doi.org/10.1016/j.tate.2014.01.006

Koskinen-Salmia, A., Haataja, E., Salonen, V., Toivanen, M., & Hannula, M. S. (2020). *Joint attention in a student group during teacher gestures*. Manuscript in preparation.

Kredel, R., Vater, C., Klostermann, A., & Hossner, E.-J. (2017). Eye-Tracking Technology and the Dynamics of Natural Gaze Behavior in Sports: A Systematic Review of 40 Years of Research. *Frontiers in Psychology, 8*. https://doi.org/10.3389/fpsyg.2017.01845

Land, M.F. (2006). Eye movements and the control of actions in everyday life. *Progress in Retinal and Eye Research, 25*(3), 296–324. https://doi.org/10.1016/j.preteyeres.2006.01.002

Lappi, O. (2016). Eye movements in the wild: Oculomotor control, gaze behavior & frames of reference. *Neuroscience & Biobehavioral Reviews, 69*, 49–68. https://doi.org/10.1016/j.neubiorev.2016.06.006

Lausberg, H., & Sloetjes, H. (2009). Coding gestural behavior with the NEUROGES-ELAN system. *Behavior Research Methods, Instruments, & Computers, 41*(3), 841–849. https://doi.org/10.3758/BRM.41.3.591

Leary, T. (1957). *Interpersonal diagnosis of personality: A functional theory and methodology for personality evaluation*. Eugene, OR: Resource Publications.

Lévesque, S., Ng-A-Fook, N., & Corrigan, J. (2014). What Does the Eye See? Reading Online Primary Source Photographs in History. *Contemporary Issues in Technology and Teacher Education, 14*(2), 101–140.

Levy, J. & Wubbels, T. (1992). Student and Teacher Characteristics and Perceptions of Teacher Communication Style. *The Journal of Classroom Interaction, 27*(1), 23–29. https://doi.org/10.1023/A:1022967927037

Määttä, O., McIntyre, N.A., Ihantola, P., Scheinin, P., & Hannula, M.S. (2020). *Teachers keep students in focus: Mobile eye-tracking to investigate mathematics teachers' gaze behavior during task instruction-giving*. Manuscript in preparation.

Magnussen, R., Zachariassen, M., Kharlamov, N., & Larsen, B. (2017). Mobile eye tracking methodology in informal E-learning in social groups in technology-enhanced science centres. *Electronic Journal of E-Learning, 15*(1), 46–58.

Mainhard, M.T., Pennings, H.J., Wubbels, T. & Brekelmans, M. (2012). Mapping control and affiliation in teacher–student interaction with State Space Grids. *Teaching and Teacher Education, 28*(7), 1027–1037. https://doi.org/10.1016/j.tate.2012.04.008

Mayer, R.E. (2004). Should there be a three-strikes rule against pure discovery learning? The case for guided methods of instruction. *American Psychologist, 59*(1), 14–19. https://doi.org/10.1037/0003-066X.59.1.14

Mayer, R.E., & Wittrock, M. (2006): Problem solving. In P. Alexander, & P. Winne (Eds.), *Handbook of educational psychology* (pp. 287-303). New York, NY: Routledge.

McCluskey, R., Dwyer, J., & Sherrod, S. (2017). Teacher immediacy and learning mathematics: Effects on students with divergent mathematical aptitudes. *Investigations in Mathematics Learning, 9*(4), 157–170. https://doi.org/10.1080/19477503.2016.1245047

McIntyre, N.A. (2016). *Teach at first sight: Expert teacher gaze across two cultural settings* (Doctoral dissertation). York, UK: University of York.

McIntyre, N.A., & Foulsham, T. (2018). Scanpath analysis of expertise and culture in teacher gaze in real-world classrooms. *Instructional Science, 46*(3), 435–455. https://doi.org/10.1007/s11251-017-9445-x

McIntyre, N.A., Jarodzka, H., & Klassen, R.M. (2019). Capturing teacher priorities: Using real-world eye-tracking to investigate expert teacher priorities across two cultures. *Learning and Instruction, 60*, 215–224. https://doi.org/10.1016/j.learninstruc.2017.12.003

McIntyre, N.A., Mainhard, M.T., & Klassen, R.M. (2017). Are you looking to teach? Cultural, temporal and dynamic insights into expert teacher gaze. *Learning and Instruction, 49*, 41–53. https://doi.org/10.1016/j.learninstruc.2016.12.005

Mehrabian, A. (1972). *Nonverbal communication*. Chicago, IL: Aldine.

Molenaar, I., van Boxtel, C., & Sleegers, P. (2010). The effects of scaffolding metacognitive activities in small groups. *Computers in Human Behavior, 26*(6), 1727–1738. https://doi.org/10.1016/j.chb.2010.06.022

Molla, T., & Nolan, A. (2020). Teacher agency and professional practice. *Teachers and Teaching, 26*(1), 67–87. https://doi.org/10.1080/13540602.2020.1740196

Mottet, T.P., Beebe, S.A., & Fleuriet, C.A. (2016). Students' influence messages. In T.P. Mottet, J.C. McCroskey, & V.P. Richmond (Eds.), *Handbook of instructional communication : rhetorical and relational perspectives* (pp. 143-166). Abingdon, UK: Routledge.

Mottet, T.P., Garza, R., Beebe, S.A., Houser, M.L., Jurrells, S., & Furler, L. (2008). Instructional communication predictors of ninth-grade students' affective learning in math and science. *Communication Education, 57*(3), 333–355. https://doi.org/10.1080/03634520801989950

Nyström, M., Niehorster, D.C., Cornelissen, T., & Garde, H. (2017). Real-time sharing of gaze data between multiple eye trackers–evaluation, tools, and advice. *Behavior Research Methods, 49*, 1310–1322. https://doi.org./10.3758/s13428-016-0806-1

O'Cathain, A. (2010). Assessing the quality of mixed methods research: Toward a comprehensive framework. In: A. Tashakkori, & C. Teddlie (Eds.), *SAGE handbook of mixed methods in social & behavioral research*

(pp. 531–556). Thousand Oaks, CA: SAGE Publications. https://doi.org/10.4135/9781506335193

O'Donnel, A. (2006).The role of peers and group learning. In P. Alexander, P. Winne (Eds.), *Handbook of educational psychology* (pp. 781–802). New York, NY: Routledge

Organisation for Economic Co-operation and Development OECD (2019). *OECD Skills Outlook 2019: Thriving in a Digital World*. Paris, France: OECD Publishing. https://doi.org/10.1787/df80bc12-en

Pekrun, R., Lichtenfeld, S., Marsh, H.W., Murayama, K. & Goetz, T. (2017). Achievement Emotions and Academic Performance: Longitudinal Models of Reciprocal Effects. *Child Development, 88*, 1653–1670. https://doi.org/10.1111/cdev.12704

Pennings, H.J.M., Brekelmans, M., Sadler, P., Claessens, L.C.A., van der Want, A.C., & van Tartwijk, J. (2018). Interpersonal adaptation in teacher-student interaction. *Learning and Instruction, 55*, 41–57. https://doi.org/10.1016/j.learninstruc.2017.09.005

Pólya, G. (1957). *How to solve it: A new aspect of mathematical method*. Princeton, NJ: Princeton University Press.

Pouta, M., Lehtinen, E., & Palonen, T. (2020). Student Teachers' and Experienced Teachers' Professional Vision of Students' Understanding of the Rational Number Concept. *Educational Psychology Review*. https://doi.org/10.1007/s10648-020-09536-y

Praetorius, A-K., McIntyre, N.A., & Klassen R.M. (2017). Reactivity effects in video-based classroom research: An investigation using teacher and student questionnaires as well as teacher eye-tracking. *Zeitschrift für Erziehungswissenschaft, 20*(1), 49–74. https://doi.org/10.1007/s11618-017-0729-3

Prieto, L.P., Sharma, K., Kidzinski, Ł., & Dillenbourg, P. (2017). Orchestration load indicators and patterns: In-the-wild studies using mobile eye-tracking. *IEEE Transactions on Learning Technologies*. https://doi.org/10.1109/TLT.2017.2690687

Prieto, L.P., Sharma, K., Wen, Y. & Dillenbourg, P. (2015): The burden of facilitating collaboration: Towards estimation of teacher orchestration load using eye-tracking measures. In: *Exploring the Material Conditions of Learning: The Computer Supported Collaborative Learning (CSCL) Conference 2015, 1*, 212-219. ISLS, Gothenburg, Sweden.

Risko, E.F., Richardson, D.C., & Kingstone, A. (2016). Breaking the fourth wall of cognitive science: Real-world social attention and the dual function of gaze. *Current Directions in Psychological Science, 25*(1), 70–74. https://doi.org/10.1177/0963721415617806

Roberts, A., & Friedman, D. (2013). The impact of teacher immediacy on student participation: An objective cross-disciplinary examination. *International Journal of Teaching and Learning in Higher Education, 25*(1), 38–46.

Rogers, S., Speelman, C., Guidetti, O., & Longmuir, M. (2018). Using dual eye tracking to uncover personal gaze patterns during social interaction. *Scientific Reports, 8*(1), 4271–4279. https://doi.org/10.1038/s41598-018-22726-7

Rojas-Drummond, S. & Mercer, N. (2003). Scaffolding the development of effective collaboration and learning. *International Journal of Educational Research, 39*(1–2), 99–111. https://doi.org/10.1016/S0883-0355(03)00075-2

Rosales, J., Vicente, S., Chamoso, J., Muñeza, D., & Orrantia, J. (2012). Teacher–student interaction in joint word problem solving: The role of situational and mathematical knowledge in mainstream classrooms. *Teaching and Teacher Education, 28*(8), 1185–1195. https://doi.org/10.1016/j.tate.2012.07.007

Roseth, C.J., Johnson, D.W., & Johnson, R.T. (2008). Promoting early adolescents' achievement and peer relationships: The effects of cooperative, competitive, and individualistic goal structures. *Psychological Bulletin, 134*(2), 223–246. https://doi.org/10.1037/0033-2909.134.2.223

Sadler, P., Ethier, N, Gunn, G., Duong, D., & Woody, E. (2009). Are we on the same wavelength? Interpersonal complementarity as shared cyclical patterns during interactions. *Journal of Personality and Social Psychology, 97*(6), 1005–1020. https://doi.org/10.1037/a0016232

Salminen-Saari, J.F.A, Garcia Moreno-Esteva, E., Haataja, E., Toivanen, M., Laine, A., & Hannula, M.S. (2020). *Joint visual attention during collaborative mathematical problem-solving through the eyes of students: A small group case study utilizing mobile gaze-tracking among Finnish 9th graders*. Manuscript submitted for publication.

Schmitz, B. (2006). Advantages of studying processes in educational research. *Learning and Instruction, 16*(5), 433–449. https://doi.org/10.1016/j.learninstruc.2006.09.004

Schulz C.M., Schneider E., Fritz L., Vockeroth J., Hapfelmeier A., Wasmaier M., Kochs E.F. & Schneider, G. (2010). Eye tracking for assessment of workload: A pilot study in an anaesthesia simulator environment. *British Journal of Anaesthesia 106*(1), 44–50. https://doi.org/10.1093/bja/aeq307

Shayan, S., Bakker, A., Abrahamson, D., Duijzer, C. & van der Schaaf, M. (2017). Eye-tracking the emergence of attentional anchors in a mathematics learning tablet activity. In: C. Was, F. Sansosti, & B. Morris (Eds.), *Eye-Tracking Technology Applications in Educational Research* (pp. 166–194). Hershey, PA: IGI Global

Shvarts, A. & Abrahamson, D. (2019). Dual-eye-tracking Vygotsky: A microgenetic account of a teaching/learning collaboration in an embodied-interaction technological tutorial for mathematics. *Learning, Culture and Social Interaction, 22*. https://doi.org/10.1016/j.lcsi.2019.05.003

Shvarts, A. & Bakker, A. (2019) The early history of the scaffolding metaphor: Bernstein, Luria, Vygotsky, and before. *Mind, Culture, and Activity, 26*(1), 4–23. https://doi.org/10.1080/10749039.2019.1574306

Smit, J., van Eerde, H.A.A. (2011). A teacher's learning process in dual design research: Learning to scaffold language in a multilingual mathematics classroom. *ZDM Mathematics Education 43,* 889–900. https://doi.org/10.1007/s11858-01

Strohmaier, A.R., MacKay, K.J., Obersteiner, A., & Reiss, K.M. (2020). Eye-tracking methodology in mathematics education research: A systematic literature review. *Educational Studies in Mathematics, 104,* 147–200. https://doi.org/10.1007/s10649-020-09948-1

Stürmer, K., Seidel, T., Müller, K., Häusler, J., & Cortina, K. S. (2017). What is in the eye of preservice teachers while instructing? An eye-tracking study about attention processes in different teaching situations. *Zeitschrift für Erziehungswissenschaft, 20*(1), 75–92. https://doi.org/10.1007/s11618-017-0731-9

Tatler, B.W., Hayhoe, M.M., Land, M.F., & Ballard, D.H. (2011). Eye guidance in natural vision: Reinterpreting salience. *Journal of Vision, 11*(5), 1–23. https://doi.org/10.1167/11.5.5

Tatler, B.W., Kirtley, C., Macdonald R.G., Mitchell, K.M.A., & Savage, S.W. (2014). The active eye: Perspectives on eye movement research. In M. Horsley, M. Eliot, B.A. Knight, & R. Reilly (Eds.), *Current trends in eye tracking research* (pp. 3–16). Cham, Switzerland: Springer.

Tchanou, A.Q., Léger, P.-M., Boasen, J., Senecal, S., Taher, J.A., & Fredette, M. (2020). Collaborative Use of a Shared System Interface: The Role of User Gaze — Gaze Convergence Index Based on Synchronous Dual-Eyetracking. *Applied Sciences, 10*(13). https://doi.org/10.3390/app10134508

Thomas, K. M., Hopwood, C. J., Woody, E., Ethier, N., & Sadler, P. (2014). Momentary assessment of interpersonal process in psychotherapy. *Journal of Counseling Psychology, 61*(1), 1–14. https://doi.org/10.1037/a0034277

Toivanen, M., Lukander, K., & Puolamäki, K. (2017). Probabilistic approach to robust wearable gaze tracking. *Journal of Eye Movement Research, 10*(4). https://doi.org/10.16910/jemr.10.4.2

Törner, G., Schoenfeld, A.H. & Reiss, K.M. (2007). Problem solving around the world: Summing up the state of the art. *ZDM Mathematics Education 39*, 353. https://doi.org/10.1007/s11858-007-0053-0

van de Pol, J., Mercer, N., & Volman, M. (2019). Scaffolding Student Understanding in Small-Group Work: Students' Uptake of Teacher Support in Subsequent Small-Group Interaction. *Journal of the Learning Sciences, 28*(2), 206–239. https://doi.org/10.1080/10508406.2018.1522258

van de Pol, J., Volman, M., & Beishuizen, J. (2010). Scaffolding in teacher-student interaction: A decade of research. *Educational Psychology Review*, *22*, 271–297. https://doi.org/10.1007/s10648-010-9127-6

van den Bogert, N., van Bruggen, J., Kostons, D. and Jochems, W.M.G. (2014): First steps into understanding teachers' visual perception of classroom events. *Teaching and Teacher Education, 37*, 208–216. https://doi.org/10.1016/j.tate.2013.09.001

van Leeuwen, A., van Wermeskerken, M., Erkens, G., & Rummel, N. (2017). Measuring Teacher Sense Making Strategies of Learning Analytics: A Case Study. *Learning: Research and Practice, 3*(1), 42–58. https://doi.org/10.1080/23735082.2017.1284252

Veneri, G., Rosini, F., Federighi, P., Federico, A. & Rufa A. (2012). Evaluating gaze control on a multi-target sequencing task: The distribution of fixations is evidence of exploration optimization. *Computers in Biology and Medicine, 42*(2), 235–244. https://doi.org/10.1016/j.compbiomed.2011.11.013

Vygotsky, L.S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Wiggins, J.S. (1991). Agency and Communion as conceptual coordinates for the understanding and measurement of interpersonal behavior. In W.M. Grove, & D. Cicchetti (Eds.), *Thinking clearly about psychology, vol. 2: Personality and psychopathology* (pp. 89–113). Minneapolis, MN: University of Minnesota Press.

Wolff, C.E. Jarodzka, H., & Boshuizen, H.P.A. (2017). See and tell: Differences between expert and novice teachers' interpretations of problematic

classroom management events. *Teaching and Teacher Education, 66*, 295–308. https://doi.org/10.1016/j.tate.2017.04.015

Wolff, C.E., Jarodzka, H., van den Bogert, N., & Boshuizen, H.P.A. (2016). Teacher Vision: Expert and Novice Teachers' Perception of Problematic Classroom Management Scenes. *Instructional Science, 44*(3), 243–265. https://doi.org/10.1007/s11251-016-9367-z

Wood, D., Bruner, J., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry, 17*(2), 89–100. https://doi.org/10.1111/j.1469-7610.1976.tb00381.x

Wubbels, T. (1993). Teacher-student relationships in science and mathematics classes. *What research says to the science and mathematics teacher*, 11, 1–8. Perth, Australia: National Key Centre for School Mathematics and Mathematics, Curtin University of Technology.

Wubbels, T., Opdenakker, M.-C., & Den Brok, P. (2012). Let's make things better. In T. Wubbels, P. Den Brok, J. Van Tartwijk, & J. Levy (Eds.), *Interpersonal relationships in education: An overview of contemporary research* (pp. 225-249). Rotterdam, The Netherlands: Sense Publishers.

Xu, L., Widjaja, W., & Ferguson, J. (2019). Seeing through the eyes of the teacher? Investigating primary school teachers' professional noticing through a video-based research methodology. *International Journal of Research & Method in Education, 42*(5), 470–484. https://doi.org/10.1080/1743727X.2018.1499016

Yamamoto, T., & Imai-Matsumura, K. (2013) Teachers' gaze and awareness of students' behavior: Using an eye tracker. *Comprehensive Psychology, 2*(6). https://doi.org/10.2466/01.IT.2.6

Yu, T.M. & Zhu, C. (2011). Relationship between teachers' preferred teacher–student interpersonal behaviour and intellectual styles. *Educational Psychology, 31*(3), 301–317. https://doi.org/10.1080/01443410.2010.548116

Zeki, C.P. (2009). The importance of non-verbal communication in classroom management. *Procedia - Social and Behavioral Sciences, 1*(1), 1443–1449. https://doi.org/10.1016/j.sbspro.2009.01.254

Zhang, Y., Pfeuffer, K., Chong, M. K., Alexander, J., Bulling, A., & Gellersen, H. (2017). Look together: Using gaze for assisting co-located collaborative search. *Personal and Ubiquitous Computing, 21*(1), 173–186. https://doi.org/10.1007/s00779-016-0969-x