Turun yliopisto
University of Turku

TOWARDS OPTIMAL SCAFFOLDING
OF LOW ACHIEVERS' LEARNING:
Combining intertwined, dynamic, and multi-domain perspectives

Anu Kajamies

University of Turku

Faculty of Education

Department of Teacher Education and Centre for Learning Research

Doctoral Programme on Learning, Teaching, and Learning Environments Research

Supervised by

Professor Marja Vauras
Department of Teacher Education
Centre for Learning Research
University of Turku, Finland

Professor Erno Lehtinen
Department of Teacher Education
Centre for Learning Research
University of Turku, Finland

Professor Simone Volet
School of Education
Murdoch University, Australia
Faculty of Education
University of Turku, Finland

Reviewed by

Professor Julianne Turner
Department of Psychology
University of Notre Dame, United States

Professor Marja-Kristiina Lerkkanen
Department of Teacher Education
University of Jyväskylä, Finland

Opponent

Professor Julianne Turner
Department of Psychology
University of Notre Dame, United States

UNIVERSITY OF TURKU
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Doctoral thesis 187 p.
Education
April 2017

Abstract

This dissertation aims to contribute to the optimal scaffolding of low achievers' learning. Scaffolding research has traditionally concentrated on teachers' short-term support and, thus, has not scrutinized the calibration of long-term support for students' learning. The aim of this dissertation is to theoretically and empirically deepen our understanding of scaffolding and learning as intertwined, dynamic, and multi-domain processes. Methodologically, the aim is to develop tools to systematically analyze intertwined multi-domain scaffolding and learning dynamics. With these tools, the opportunities created and taken up during interactions by both low achievers and their teachers are scrutinized and integrated to unveil both low achievers' readiness for challenges and teachers' flexibility in calibrating scaffolding to students' needs. On a practical level, by developing and identifying scaffolding practices, this dissertation aims to promote and explore teachers' professional development in optimal scaffolding. To achieve these aims, this dissertation comprises four intervention studies. The mixed methods approach, including carefully designed tests, quasi-experimental and single-subject designs, and longitudinal in-depth case studies with systematic interaction video-observations, was used in the studies.

In Study I, the aim was to determine the effectiveness of multi-domain scaffolding in supporting low achievers' learning. We designed an intervention to develop the cognitive–metacognitive and motivational–emotional domains needed in mathematical word problem solving. To overcome challenges reported in earlier studies on scaffolding low achievers' complex skills, our intervention combined teacher scaffolding with word problems embedded in a computer-supported adventure game. During the instructional discussions, the students were scaffolded to become active, strategic, and motivated problem solvers. Altogether, 429 general education fourth grade 10-year-old students participated. Intervention students ($n = 8$) and two pairwise-matched controls for each intervention student ($n = 16$) were selected from the low

achievers in word problem solving among the total sample. Intervention students participated in the intervention in pairs during 14 game lessons. Each lesson lasted approximately 45 minutes. At the group level, some positive and lasting effects for the intervention group's word problem solving were indicated by the statistical test results and effect sizes from the pre-test, post-test, and follow-up test comparisons. After the intervention, the intervention group's word problem solving skills no longer differed from those of the other students (n = 405), who served as a comparison group to establish the typical skill level of the age group. By contrast, the control groups' skills still were below the typical level. When the individual learning dynamics behind the group level were scrutinized, large intra- and inter-individual variability were identified. Observations showed the power of the innovative learning environment in deepening students' engagement in problem solving, but also the challenges in scaffolding low achievers' complex skills. It was concluded that low achievers' word problem solving skills progress when they are given intensive and systematic multi-domain teacher scaffolding in a carefully designed computer-supported learning environment. The interesting variability in the low achievers' development and the vital role of the instructional discussion between the low achievers and the teacher highlighted the importance of in-depth analysis of multi-domain scaffolding interactions to deepen our understanding of the most optimal ways to scaffold low achievers and formed the basis of Studies II to IV.

In Study II, the aim was to establish the potential of dynamic interaction analysis to study scaffolding. We introduced an educational application of the State Space Grid (SSG) method for analyzing teachers' scaffolding in relation to students' learning in real time. We also built a theoretically integrated optimal scaffolding model that uses concepts of interpersonal positioning, creation, and the take-up of opportunities to interpret interactions illustrated with SSGs. Based on the optimal scaffolding model, during scaffolding, students are positioned by moment-to-moment opportunities to participate in particular ways. Over time, these interpersonal positions establish diverse learning trajectories. To successfully support learning in the cognitive–metacognitive domain, scaffolding was supposed to include both dynamic matches between opportunities created by the teacher and taken up by the students and opportunities created by the teacher at a higher level than the students' following participation. Methodological illustrations were produced by analysing from videotapes the strategic levels of opportunities created and taken up between a special education teacher and three fourth-grade low achievers during three lessons in a multi-domain small-group reading comprehension intervention. The results showed that teacher domination and interaction at low matched levels were very typical. Interactions at high levels were rare. Missed opportunities were observed when the teacher created high-level opportunities, but faced challenges in pulling low achievers to this level or failed to take up opportunities created by the low achievers. These missed opportunities showed that the teacher had difficulties calibrating her level of scaffolding to pull the low

achievers toward new levels of independent activity. With these methodological illustrations, we established the power of SSGs for representing and analyzing instructional match and mismatch in the cognitive–metacognitive domain. We also showed that studying scaffolding interactions has great potential for understanding teachers' expertise and the dynamics behind resistance and resilience to learning. The methodological and theoretical progress made in Study II formed the basis for scrutinizing long-term scaffolding interactions with more cases in Study III.

In Study III, the aim was to deepen understanding of the intertwined and dynamic nature of evolving scaffolding patterns in the cognitive–metacognitive domain. We further developed the optimal scaffolding model and applications of the SSG method for studying long-term scaffolding. To capture opportunities created and taken up during extended processes, all intervention lessons in two small groups were analyzed from videotapes (19 lessons/group, altogether 21,428 contributions). Both groups participated in the reading comprehension intervention developed in Study II, and interactions were analysed in the same way as in Study II. The results demonstrated that low-level matches were too typical and high-level matches too rare also during long-term scaffolding. Based on the optimal scaffolding model, we expected an increase in high-level matches and a decrease in low-level matches during the intervention. However, there were no linear changes in the matched interactions. The most promising but, unfortunately, frequently missed potential emerged when the teacher or the low achievers created opportunities by participating at a higher level than the other participant. We expected an increase in opportunities created by the teacher during the intervention. However, one of the two teachers did not increase and the other even decreased high-level opportunities. Interestingly, there was a linear increase in the high-level opportunities created by the low achievers in both groups. Unfortunately, the teachers did not flexibly take up the low achievers' increasing readiness for high-level participation. Interesting group differences, fluctuations and non-linear developments were also found. This study deepened our understanding of the intertwined and dynamic nature of cognitive–metacognitive scaffolding and emphasized the need to continue developing collaborations between researchers and teachers to increase optimal scaffolding. Future research was challenged to understand the scaffolding in both the cognitive–metacognitive and the motivational–emotional domains to deepen the understanding of the systemic formation and maintenance of learning dynamics. In Study IV, we took the next step towards this grand goal by scrutinizing teachers' emotional scaffolding.

In Study IV, the aim was to gain insight into the nature and evolution of scaffolding in the motivational–emotional domain. We developed a systematical observation method to deepen the understanding of teachers' emotional scaffolding and its variation during interaction processes. Methodological illustrations were produced by analysing from videotapes the teachers' emotional support in a multi-domain dialogic story reading

intervention. Videos from four preschool teachers were used to develop emotional support categories based on the Classroom Assessment Scoring System. Using the developed categories, we observed the positive, neutral, and negative emotional support of the other two preschool teachers, called here Petra and Leena, developmentally across the intervention during three sessions, variation of emotional support during single reading sessions and typical expressions of emotional support. The results showed that both preschool teachers provided mainly positive or neutral emotional support and seldom negative emotional support. Leena provided more positive emotional support and had more and longer consistent phases in her emotional support than Petra, whose emotional support was mainly neutral. However, Leena's emotional support showed more inter-session variation than Petra's. Consistent, harmful-to-learning phases (variations between negative and neutral emotional support) were observed in Petra's mainly neutral emotional support in each session. Positive emotional support typically manifested as engaged reading, positive feedback, and encouraging facial expressions. Negative emotional support was typically shown by insensitivity and inflexibility to the children's perspectives. With the help of the systematic observation method, it was possible to scrutinize the differences between the cases and both the stability and the variability of emotional support. The developed emotional support classification offers an in-depth method for recognizing the strengths and weaknesses of emotional support. Applying this classification to other kinds of interaction contexts, skill levels, and age groups would increase the understanding of emotional support in different contexts. In the future, emotional interaction could also be investigated from the perspective of the children to deepen the understanding of the complex systemic nature of emotional interactions by showing how children's participation is intertwined with emotional support.

Taken together, the four studies demonstrated that, to progress towards optimal scaffolding of low achievers' learning, scaffolding needs to be scrutinized not only theoretically, but also empirically by combining intertwined, dynamic, and multi-domain perspectives. Variability of learning dynamics within and between students emphasizes that the careful, on-going calibration of the multi-domain support from the teacher and the learning environment are vital in optimally scaffolding each student's progress towards learning goals during long-term interventions. New methods developed to systematically analyze and represent educationally meaningful multi-domain interaction patterns revealed several challenges in scaffolding low achievers. Low-level matches were too typical and high-level matches too rare. This highlights a need to strengthen teachers' skills in scaffolding students' take-up of high-level opportunities, which are pivotal for their learning of complex cognitive–metacognitive skills. Teachers should also sensitively listen to and flexibly follow up on opportunities created by their students by joining them in interactions directed towards the learning goals. The scaffolding interactions did not gradually move towards high levels even though it was expected to happen during the long-term intervention. The low achievers

showed increasing readiness for high-level participation; however, unfortunately, this was not flexibly taken up by the teachers. Based on the findings of this dissertation, we need to carefully consider how to optimally spend the precious time we can afford for scaffolding low achievers. The scaffolding interactions should focus on or at least gradually move towards focusing on high strategic and meta-strategic levels during long-term processes. To construct optimal cognitive–metacognitive scaffolding backed by consistent positive emotional support, we also need to pay greater attention to emotional support. Otherwise, the limited resources are non-optimally used for supporting low achievers' learning of complex skills.

Tiivistelmä

Tämä väitöskirja pyrkii edistämään oppimisvaikeusoppilaiden oppimisen optimaalista ohjaamista. Ohjausvuorovaikutustutkimus on perinteisesti keskittynyt opettajien lyhytkestoiseen tukeen eikä ole huolellisesti tarkastellut ohjauksen yhteensovittumista oppilaiden oppimisen kanssa pitkäkestoisissa prosesseissa. Tämän väitöskirjan tavoitteena on teoreettisesti ja empiirisesti syventää ymmärrystämme ohjauksesta ja oppimisesta yhteenkietoutuneina, kehityksellisesti vaihtelevina ja moniulotteisina prosesseina. Menetelmällisesti tavoitteena on kehittää välineitä systemaattisesti analysoida ohjauksen ja oppimisen yhteenkietoutunutta moniulotteista dynamiikkaa. Näiden välineiden avulla tarkastellaan ja integroidaan sekä oppimisvaikeusoppilaiden että opettajien luomia ja toteuttamia mahdollisuuksia. Näin voidaan selvittää sekä oppimisvaikeusoppilaiden valmiutta tarttua haasteisiin että opettajien joustavuutta sovittaa ohjaustaan oppilaiden oppimistarpeisiin. Käytännön tavoitteena on edistää opettajien ammatillista kehittymistä optimaalisen ohjausvuorovaikutuksen toteuttamisessa tunnistamalla ja kehittämällä oppimisen ohjaustapoja. Näiden tavoitteiden saavuttamiseksi väitöskirja koostuu neljästä opetuskokeilututkimuksesta, joissa käytettiin monimenetelmäistä lähestymistapaa. Menetelmällisiin ratkaisuihin sisältyi huolellisesti suunniteltuja testejä, näennäiskokeellinen asetelma, yksittäistapaustutkimusasetelma sekä syvälle luotaavia pitkittäistapaustutkimuksia, joissa vuorovaikutusta havainnointiin systemaattisesti videoilta.

Tutkimuksessa I tavoitteena oli arvioida moniulotteisen ohjauksen tehokkuutta oppimisvaikeusoppilaiden oppimisen tukemisessa. Suunnittelimme opetuskokeilun kehittämään matemaattisessa ongelmanratkaisussa tarvittavia kognitiivis–metakognitiivisia ja motivationaalis–emotionaalisia ulottuvuuksia. Opetuskokeilussamme opettajan ohjaus yhdistettiin seikkailulliseen tietokonepeliin sijoitettuihin sanallisiin ongelmanratkaisutehtäviin, jotta voitiin yrittää vastata aikaisemmissa tutkimuksissa

esille nostettuihin haasteisiin oppimisvaikeusoppilaiden oppimisen ohjaamisessa. Opetuskeskusteluissa oppilaita ohjattiin aktiivisiksi, strategisiksi ja motivoituneiksi ongelmanratkaisijoiksi. Tutkimukseen osallistui 429 yleisopetuksen 4. luokkalaista. Opetuskokeiluun osallistuvat oppilaat (n = 8) ja jokaiselle kaksi mahdollisimman soveltuvaa vertailuoppilasta (n = 16) valittiin sellaisista tutkimukseen osallistuneista oppilaista, joilla oli vaikeuksia sanallisten ongelmien ratkaisemisessa. Oppilaat osallistuivat opetuskokeiluun pareittain neljällätoista noin 45 minuutin pelikerralla. Myönteisiä ja pysyviä vaikutuksia opetuskokeiluun osallistuneiden ongelman-ratkaisutaitoihin havaittiin ryhmätasolla alku- ja loppumittauksen sekä viivästetyn mittauksen tilastollisten testausten ja vaikutusten kokojen perusteella. Opetuskokeilun jälkeen siihen osallistuneen ryhmän ongelmanratkaisutaidot eivät enää eronneet ikäryhmän tyypillisestä tasosta (n = 405), mutta kontrolliryhmien taidot olivat edelleen tyypillistä tasoa alhaisemmat. Tarkasteltaessa yksilöiden kehitystä ryhmätason taustalla havaittiin suurta yksilöiden välistä ja sisäistä vaihtelua. Opetuskokeilun aikaiset havainnot osoittivat innovatiivisen oppimisympäristön voiman oppilaiden syvälliseen ongelmanratkaisuun sitoutumisen lisäämisessä, mutta myös haasteita oppimisvai-keusoppilaiden monimutkaisten taitojen oppimisen ohjaamisessa. Tulosten perusteella oppimisvaikeusoppilaat kehittyvät sanallisessa ongelmanratkaisussa, kunhan tarjotaan intensiivistä, systemaattista ja moniulotteista opettajan ohjausta huolellisesti suunnitellussa tietokoneavusteisessa oppimisympäristössä. Oppilaiden kehityserot ja opetuskeskustelun keskeisyys korostivat ohjausvuorovaikutuksen huolellisen analysoinnin tärkeyttä pyrkiessämme syventämään ymmärrystä optimaalisimmista tavoista ohjata oppimisvaikeusoppilaiden oppimista sekä muodostivat pohjan tutkimuksille II-IV.

Tutkimuksessa II tavoitteena oli osoittaa kehitykselliseen tarkasteluun soveltuvan vuorovaikutusanalyysin mahdollisuudet ohjausvuorovaikutuksen tutkimisessa. Esittelimme opetuksellisen sovelluksen vuorovaikutusruudukosta (State Space Grid), jolla voidaan tutkia opettajan ohjausta suhteessa oppilaiden osallistumisiin reaaliajassa. Kehitimme myös teoreettisesti integroidun lähestymistavan, joka käyttää käsitteitä yksilöiden välinen asemointi sekä mahdollisuuksien luominen ja toteutuminen tulkitessaan vuorovaikutusruudukkoa. Lähestymistapamme perusteella ohjausvuoro-vaikutuksessa hetki-hetkeltä luodut mahdollisuudet asemoivat oppilaita osallistumaan tietyin tavoin. Ajan kuluessa yksilöiden väliset asemat vakiintuvat muodostaen erilaisia oppimispolkuja. Onnistunut kognitiivis–metakognitiivinen ohjausvuorovaikutus edellyttää sekä jatkuvasti uudelleen määrittyvää yhteensopivuutta opettajan luomien mahdollisuuksien ja oppilaiden toteumien välillä että opettajan luomia mah-dollisuuksia, jotka ovat korkeammalla tasolla kuin oppilaiden sen hetkinen osallistuminen. Menetelmällisiä esimerkkikuvauksia tuotettiin analysoimalla videoilta erityisopettajan ja kolmen 4. luokkalaisen oppimisvaikeusoppilaan luomien ja toteuttamien mahdollisuuksien strategisia tasoja. Analyysi kohdistui kolmeen pienryhmässä toteutettuun moniulotteisen luetun ymmärtämisen opetuskokeilun

oppituntiin. Tulokset osoittivat, että opettajan dominointi sekä opettajan ja oppimisvaikeusoppilaiden vuorovaikutus samalla alhaisella tasolla olivat erittäin tyypillisiä. Vuorovaikutus korkeilla tasoilla sen sijaan oli harvinaista. Menetettyjä mahdollisuuksia havaittiin, kun opettaja loi mahdollisuuksia korkealla tasolla, mutta ei saanut oppimisvaikeusoppilaita tälle tasolle tai epäonnistui oppilaiden luomiin mahdollisuuksiin tarttumisessa. Menetetyt mahdollisuudet osoittivat, että opettajalla oli vaikeuksia johdonmukaisesti nostaa ohjaustasoaan kohti oppimisvaikeusoppilaiden uusia itsenäisen toiminnan tasoja. Menetelmällisten kuvausten avulla osoitimme vuorovaikutusruudukoiden voiman kognitiivis–metakognitiivisen ohjausvuorovaikutuksen osallistumisten yhteensopivuuden ja -sopimattomuuden kuvaamisessa ja analysoinnissa. Osoitimme myös, että ohjausvuorovaikutusten tutkiminen tarjoaa mahdollisuuden ymmärtää paremmin opettajan asiantuntijuutta sekä oppimisen onnistumisiin ja haasteisiin liittyvää ohjausvuorovaikutusta. Tutkimuksen menetelmälliset ja teoreettiset edistysaskeleet muodostivat perustan ohjausvuorovaikutusten entistä systemaattisemmalle tutkimiselle pidempien vuorovaikutusprosessien aikana useammissa esimerkkitapauksissa tutkimuksessa III.

Tutkimuksessa III tavoitteena oli syventää ymmärrystä kognitiivis–metakognitiivisten ohjausvuorovaikutuksen yhteenkietoutuneesta ja kehityksellisesti vaihtelevasta luonteesta. Kehitimme edelleen teoreettista malliamme optimaalisesta ohjausvuorovaikutuksesta sekä vuorovaikutusruudukon (State Space Grid) käyttötapoja, joilla voidaan tutkia pitkäkestoista ohjausvuorovaikutusta. Jotta voitiin tavoittaa pitkällä aikavälillä luotuja ja toteutuneita mahdollisuuksia, kahden ryhmän kaikki opetuskokeilun oppitunnit analysoitiin (19 tuntia/ryhmä, yhteensä 21 428 osallistumista). Ryhmät osallistuivat samaan luetun ymmärtämisen opetuskokeiluun kuin ryhmä tutkimuksessa II ja samoja strategisen osallistumisen luokkia käytettiin analysoitaessa osallistumisten tasoja. Tulokset osoittivat, että opettajan ja oppilaiden vuorovaikutus samalla alhaisella tasolla oli liian tyypillistä ja vuorovaikutus samalla korkealla tasolla liian harvinaista myös pitkän aikavälin ohjausvuorovaikutuksessa. Optimaalisen ohjausvuorovaikutuksen mallimme perusteella oletimme, että opetuskokeilun aikana vuorovaikutus samalla korkealla tasolla lisääntyisi ja vuorovaikutus samalla matalalla tasolla vähenisi. Kuitenkaan vuorovaikutuksissa samalla tasolla ei tapahtunut lineaarisia muutoksia. Lupaavinta, mutta valitettavasti usein toteutumatta jäänyttä oppimispotentiaalia ilmeni kun opettaja tai oppilaat loivat mahdollisuuksia osallistumalla toista vuorovaikutukseen osallistujaa korkeammalla tasolla. Optimaalisen ohjausvuorovaikutuksen mallimme perusteella oletimme, että opetuskokeilun aikana opettajan luomat mahdollisuudet lisääntyisivät. Kuitenkin toinen opettajista ei lisännyt ja toinen jopa vähensi luomiaan korkeatasoisia mahdollisuuksia. Sen sijaan oppilaiden luomat korkeatasoiset mahdollisuudet lisääntyivät molemmissa ryhmissä. Valitettavasti opettajat eivät joustavasti tarttuneet oppilaiden lisääntyneeseen valmiuteen korkeatasoisiin osallistumisiin. Vuorovaikutuksissa samalla tasolla ja mahdollisuuksissa havaittiin myös mielenkiintoisia ryhmien

välisiä eroja, satunnaista vaihtelua ja ei-lineaarista kehitystä. Tämä tutkimus syvensi ymmärrystämme kognitiivis–metakognitiivisen ohjausvuorovaikutuksen yhteenkietoutuneesta ja kehityksellisesti vaihtelevasta luonteesta sekä korosti tarvetta jatkaa opettajien kanssa tehtävän yhteistyön kehittämistä optimaalisen ohjausvuorovaikutuksen lisäämiseksi. Jatkotutkimuksen haasteeksi asetettiin ymmärtää ohjausvuorovaikutusta sekä kognitiivis–metakognitiivisella että motivationaalis–emotionaalisella ulottuvuudella. Tutkimuksessa IV otimme seuraavan askeleen kohti tätä suurta tavoitetta tarkastelemalla opettajan emotionaalista ohjausta.

Tutkimuksessa IV tavoitteena oli tarkentaa näkemystä oppimisen ohjauksen luonteesta ja kehityksestä motivationaalis–emotionaalisella ulottuvuudella. Kehitimme systemaattisen havainnointimenetelmän syventääksemme ymmärrystä tunnetuesta ja sen vaihtelusta vuorovaikutusprosesseissa. Menetelmällisiä esimerkkikuvauksia tuotettiin analysoimalla tunnetukea videoilta moniulotteisen keskustelevan lukemisen opetuskokeilun aikana. Neljän lastentarhanopettajan videoita käytettiin kehitettäessä tunnetuen luokkia luokkahuonehavainnointiin tarkoitetun CLASS-menetelmän pohjalta. Kehittämämme luokittelun avulla havainnoimme kahden, tässä Petraksi ja Leenaksi nimetyn, lastentarhanopettajan myönteistä, neutraalia ja kielteistä tunnetukea kehityksellisesti kolmessa tuokiossa opetuskokeilun aikana. Lisäksi tarkastelimme heidän tunnetukensa vaihtelua yksittäisten lukutuokioiden aikana ja tyypillisiä tunnetuen ilmenemismuotoja. Tulokset osoittivat, että molemmat lastentarhanopettajat tarjosivat pääosin myönteistä tai neutraalia tunnetukea, kielteisen tunnetuen jäädessä vähäiseksi. Leena tarjosi enemmän myönteistä tunnetukea ja hänellä johdonmukaisia, oppimista tukevia ohjausjaksoja oli enemmän ja ne olivat pidempiä kuin Petralla, jonka tunnetuki oli pääosin neutraalia. Leenan tunnetuki vaihteli kuitenkin tuokioiden välillä enemmän kuin Petran. Oppimista haittaavaa johdonmukaisuutta eli jatkuvaa vaihtelua neutraalin ja kielteisen tunnetuen välillä ilmeni Petran pääosin neutraalin tunnetuen taustalla joka tuokiossa. Myönteinen tunnetuki ilmeni tyypillisesti eläytyvänä lukemisena, myönteisenä palautteena ja kannustavina ilmeinä. Kielteinen tunnetuki ilmeni tyypillisesti joustamattomuutena lasten näkökulmille. Systemaattisen havainnointimenetelmän avulla voitiin tutkia opettajien välisiä eroja sekä tunnetuen vaihtelua ja pysyvyyttä. Tunnetukiluokittelu tarjoaakin perusteellisen välineen tunnistaa tunnetuen vahvuuksia ja heikkouksia. Luokittelun soveltaminen muunlaisiin vuorovaikutuksiin, taitotasoihin ja ikäryhmiin lisäisi ymmärrystä tunnetuesta eri ympäristöissä. Tulevaisuudessa tunnetukea pitäisi tutkia myös lasten näkökulmasta, jotta voidaan syventää ymmärrystä tunnevuorovaikutusten monimutkaisesta systeemisestä luonteesta osoittamalla, miten lasten osallistuminen on kietoutunut tunnetukeen.

Yhteenvetona neljä tutkimusta osoittavat, että eteneminen kohti oppimisvaikeus-oppilaiden oppimisen optimaalista ohjausta edellyttää ohjausvuorovaikutuksen tarkastelua—ei vain teoreettisesti vaan myös käytännössä—yhteenkietoutuneisuuden, dynaamisuuden ja moniulotteisuuden näkökulmia yhdistellen. Oppilaiden välinen ja

sisäinen oppimisvaihtelu korostavat opettajan ja oppimisympäristön moniulotteisen tuen huolellisen ja jatkuvan yhteensovittamisen tärkeyttä, jotta voidaan tukea jokaisen oppilaan etenemistä kohti oppimistavoitteita pitkäkestoisten opetuskokeilujen aikana. Opetuksellisesti merkityksellisten vuorovaikutuskulkujen analysointiin kehittämämme uudet menetelmät paljastivat useita haasteita oppimisvaikeusoppilaiden oppimisen ohjauksessa. Opettajan ja oppilaiden vuorovaikutus samalla alhaisella tasolla oli liian tyypillistä ja samalla korkealla tasolla liian harvinaista. Tämä korostaa tarvetta vahvistaa opettajien taitoja tukea oppilaita korkeatasoisiin mahdollisuuksiin tarttumisessa, joka on ratkaisevaa monimutkaisten kognitiivis–metakognitiivisten taitojen oppimisen kannalta. Opettajien tulisi myös herkästi kuunnella ja joustavasti jatkaa oppilaidensa luomia mahdollisuuksia liittämällä ne osaksi oppimistavoitteisiin tähtäävää vuorovaikutusta. Ohjausvuorovaikutus ei vähitellen siirtynyt kohti korkeampia tasoja, vaikka niin oletettiin pitkäkestoisen opetuskokeilun aikana tapahtuvan. Oppimisvaikeusoppilaat osoittivat lisääntynyttä valmiutta korkeatasoiseen osallistumiseen, mutta valitettavasti opettajat eivät joustavasti tarttuneet tähän mahdollisuuteen. Tulostemme perusteella pitää huolellisesti harkita, miten käytetään optimaalisesti se vähäinen, mutta kuitenkin ainutlaatuisen merkityksellinen aika, joka voidaan käyttää oppimisvaikeusoppilaiden tukemiseen. Monimutkaisten taitojen oppimiseen tähtäävän ohjausvuorovaikutuksen tulisi painottua tai ainakin vähitellen pitkäkestoisten prosessien aikana siirtyä yhä enemmän korkeille strategisille ja meta-strategisille tasoille. Jotta optimaalista kognitiivis–metakognitiivista ohjausvuoro-vaikutusta vahvistettaisiin johdonmukaisella myönteisellä tunnetuella, myös tunnetukeen tulisi kiinnittää enemmän huomioita. Muuten rajallisia resursseja ei käytetä optimaalisesti oppimisvaikeusoppilaiden monimutkaisten taitojen oppimisen tukemiseen.

Asiasanat: opettajan ja oppilaiden välinen ohjausvuorovaikutus, optimaalinen oppimisen ohjaus, oppimisvaikeusoppilaat, luodut ja toteutuneet mahdollisuudet, oppimisdynamiikka, pitkittäistapaustutkimus, ymmärtämistaidot, sanallisten ongelmien ratkaisu

Contents

Acknowledgements

scaffolding model and dynamic systems methods of this dissertation, Pekka Salonen, for his passion to understand complexities of teacher–student interactions.

I also want to thank my co-writer Aino Mattinen for reminding me always to look from the positive perspective. Collaboration with Aino, especially when implementing Bunny Stories, has advanced my understanding of scaffolding teachers' professional development and young children's learning. I also thank my co-writers Maria-Loviisa Kaurila and Emma Lehtonen. I was inspired by Maria-Loviisa's and Emma's curiosity as future classroom teachers to deepen their understanding of emotional support.

My warm thanks belong to Tuike Iiskala, Minna Hannula-Sormunen, Marjaana Veermans, and Janne Lepola for long-term collaboration and friendship. Tuike's dissertation has been the most important guideline for me to write my own. I also thank Eero Laakkonen for his expert statistical support and Niina Junttila for collaboration during the Quest for Meaning project. Working as a teacher in the Department of Teacher Education has created special opportunities for me to increase my expertise in teaching. I am especially grateful for Kristiina Heikkilä, Mirjamaija Mikkilä-Erdmann, Teija Holst and Arja Virta, for their support in my attempts to develop my teaching practices.

All teachers, daycare professional, students and children who participated in the Quest for Meaning project and Bunny Stories project are entitled to special thanks, because they made the empirical parts of this dissertation possible and enjoyable.

I am forever grateful for my parents Pirjo and Elias for their support in my studies and teaching me the importance of persistence and hard high-quality work. I also want to thank my brother Mika and sister Marja and their families for opportunities to forget work and become part of their children's deeply engaged free time activities. Finally, I want to express my deepest gratitude to my husband Timo and son Veikka for their patience and invaluable support for my work.

In Vanhalinna, March 2017

List of empirical studies

This doctoral dissertation is based on the following four studies, which are reported in four original publications. The publishers have granted permissions for the use of these respective publications in this dissertation. The studies are referenced in the text by their Roman numerals.

Study I   Kajamies, A., Vauras, M., & Kinnunen, R. (2010). Instructing low-achievers in mathematical word problem solving. *Scandinavian Journal of Educational Research, 54(4),* 335-355.

                 Kajamies contributed to the study conception and design. She was responsible for the data collection and analysis, implementation of the intervention, and writing of the manuscript.

Study II   Vauras, M., Kinnunen, R., Kajamies, A., & Lehtinen, E. (2013). Interpersonal regulation in instructional interaction: A dynamic systems analysis of scaffolding. In S. Volet & M. Vauras (Eds.), *Interpersonal regulation of learning and motivation. Methodological advances* (pp. 125–146). New perspectives on learning and instruction. NY: Routledge.

                 Kajamies was responsible for developing the dynamic interaction analysis used to study scaffolding and was involved in building the theoretical approach to interpret the analysis results.

Study III   Kajamies, A., Vauras, M., Kinnunen, R., Lehtinen, E., & Volet, S. (in review). Intertwined and dynamic scaffolding of low achievers' reading comprehension strategies.

                 Kajamies was responsible for the study conception and design, data collection and analysis, and writing of the manuscript.

Study IV   Kajamies, A., Mattinen, A., Kaurila, M.-L., & Lehtonen, E. (2016). Emotional support constructing high quality scaffolding in day care. *Journal of Early Childhood Education Research, 5(1)*, 162–188.

                 Kajamies was responsible for the study conception and design. She also wrote the manuscript and contributed to the data collection and analysis.

1. Introduction

The main aim of this dissertation is to scrutinize the optimal scaffolding of low achievers' learning, which is one of the pending challenges in the educational research and practice (Gresalfi, 2009; Van de Pol & Elbers, 2013; Vauras, Salonen, Lehtinen, & Kinnunen, 2009). This dissertation aims to theoretically and empirically deepen our understanding of scaffolding to face the challenges of scaffolding low achievers' learning.

Scaffolding is an important and frequently used concept in educational research. However, no consensus has been reached with respect to its definition (reviews by Stone, 1998; Van de Pol, Volman, & Beishuizen, 2010). Typically scaffolding is defined as carefully calibrated teacher support that creates opportunities for students to achieve goals beyond what would be possible through their unsupported efforts (Muhonen, Rasku-Puttonen, Pakarinen, Poikkeus, & Lerkkanen, 2016; Steenbeek, Jansen, & Van Geert, 2012; Van de Pol, Volman, Oort, & Beishuizen, 2014; Wood, Bruner, & Ross, 1976). This theoretical definition emphasizes the **intertwined** nature of teachers' scaffolding and students' learning. The following translated and shortened transcripts from our reading comprehension interventions (Studies II and III) also empirically illustrate the intertwined nature of the teachers' and students' contributions. **Transcript 1** is from the first lesson, during which the teacher's (Anna's[1]) goal was to scaffold low achievers (Jani, Hannu, and Ari) in understanding the word 'strategy' and the usefulness of strategies in reading comprehension.

> Anna: Now we will be detective readers and we will learn a new word. This is our secret keyword and it helps us in difficult reading tasks. This word is 'strategy'.
> Jani: I have heard it in ice hockey commentaries. Commentators discuss about strategies.
> Anna: Yes, true. Jani has heard that in ice hockey games they talk about strategies. Have you heard about strategies, Hannu?
> Hannu: Yes, I have somewhere, but I do not remember.
> Ari: I have heard it in game evaluations. There it is said that the evaluations are of strategy games.
> Anna: Yes.

In Transcript 1, Jani and Ari contributed to the interaction by sharing their earlier experiences of the word 'strategy' in game and sports contexts. The teacher contributed to the interaction by introducing a new topic, listening to the students' experiences, approving them, and asking Hannu also to share his experiences. These intertwined contributions set the stage for the calibration of the scaffolding, since the teacher knew that two of her students had earlier experiences with the word 'strategy' and one

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[1]The names of all participants have been changed to preserve anonymity.

student did not. The guidebook provided for the teachers to support their scaffolding during the intervention asked the teachers to always calibrate their explanations to their students' experiences and gave examples from different contexts. For example, in this task, the guidebook gave examples of the meaning of the word 'strategy' in contexts of war, games and sports. **Transcript 2** shows how the interaction continued.

> Anna: The word 'strategy' means plans, means, and different ways of achieving good results. We can compare it to war commanders, who need to have good strategies.
> Ari: Strategy is like a fight, an exciting fight.
> Jani: It is not.
> Anna: Hmm…
> Hannu: Strategy means ways to steer the car in the curves.
> Anna: Yes. With these strategies that I teach you and we practice together, we will improve reading comprehension in this project. This is the main goal of our work in this little group during this spring. It is very nice that we can practice reading comprehension together.
> Anna gives notebooks to the students and asks them to draw colorful detectives to their notebooks.
> Anna: You can yourself decide what kind of detective you want to draw.
>
> Students start drawing enthusiastically.

When scrutinizing the quality of scaffolding, it is crucial to examine the care with which the teacher's support is calibrated to the students' learning. In Transcript 2, the teacher did not ask the students to explain their understanding of the word 'strategy' on the basis of their experiences in the game and sports contexts, but instead tried to explain the word 'strategy' by connecting it to a war context. Ari's misunderstanding and the other students' short and vague comments showed that the teacher faced challenges in calibrating her support to extend the students' understanding of the new word beyond what would be possible without her support. Given these challenges, the teacher did not persist with the calibration, but gave up and moved into drawing context, where the group spent time drawing and discussing the details of drawings that were unrelated to the goals of the intervention.

In Transcript 2, the teacher supported progress towards another goal of the lesson—understanding the usefulness of strategies in reading comprehension—only briefly ("With these strategies that I teach you and we practice together, we will improve reading comprehension in this project.") and without any elaborations. The calibration of this scaffolding attempt was left unclear during the lesson because no intertwined student contributions were observed that could be used to evaluate how the students understood the usefulness of strategies in reading comprehension. Furthermore, the teacher defined practicing strategies as their long-term goal. This means that, in order to understand the care with which the teacher's scaffolding was calibrated to the students' learning, the evolution of the teacher's scaffolding and the students' learning needed to be followed for an extended period of time. This highlights not only the

intertwined nature of scaffolding, but also its **dynamic** nature. Doing justice to intertwined scaffolding dynamics calls for insight into the development of students' learning, teachers' scaffolding, and scaffolding interactions[2] over time (Cash & Pianta, 2014; Mercer & Dawes, 2014; Pennings & Mainhard, 2016; Praetorius, Pauli, Reusser, Rakoczy, & Klieme, 2014; Rojas-Drummond, Torreblanca, Pedraza, Vélez, & Guzmán, 2013; Turner & Nolen, 2015). The following shortened **Transcript 3** from our reading comprehension interventions gives an empirical illustration of intertwined scaffolding dynamics from the last (19th) lesson, during which the teacher's goal was to scaffold low achievers in the effective use and flexible application of all reading comprehension strategies practiced during the intervention.

> Anna: Let's think about homework situations where you need to learn new things. How do you read the texts, for example, from science books?
> Ari: I always read everything and then select the main ideas to remember. Summaries in the text also help me to remember, since the main ideas are condensed there.
> Anna: Yes. How about you, Jani?
> Jani: I also read everything and then the summaries.
> Anna: Yes. All main ideas are included in the summary. We also made here a summary of the book we had read by using the strategies we have practiced. We used our earlier knowledge to clarify things. We also selected the main ideas and combined them. It is not enough to select the main ideas. You also need to combine them. Then, we also monitored our understanding. Do you remember what we did when the text included a difficult word? What did we do?
> Hannu: Stop and think.
> Anna: Stop and think, yes! In a difficult place, stop and think. If you just go on, is it easy to understand and learn the text?
> Hannu: No.
> Jani: No.
> Anna: Really no. Stop and think is important to keep in mind. And I'm sure you will remember that.

In Transcript 3, the teacher asked the students to describe how they read texts in other reading contexts and reminded the students about the reading comprehension strategies they had practiced. The teacher's scaffolding here was more carefully calibrated to the students' learning than it was during the first lesson, since examples were now drawn from a familiar homework context and from the students' earlier intervention tasks. All students contributed to the interaction and showed what they had learned about reading comprehension strategies. Without following the evolution of the students' learning, the teacher's scaffolding, and the scaffolding interactions over time—at least once, as

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[2]The term 'scaffolding interaction' is used to emphasize the intertwined nature of students' learning and teachers' scaffolding. This emphasis was seen important, since empirically the focus of scaffolding research has typically been on teachers (Van de Pol et al., 2010), even though definitions of scaffolding highlight the intertwined nature of the teachers' and students' contributions.

in these transcripts—interesting developmental dynamics could have been more difficult, if not impossible, to capture. Naturally, insight into the intertwined dynamics of achieving challenging goals, such as the effective use and flexible application of strategies, calls for more in-depth and long-term analysis of scaffolding over time than just these snapshots of interactions from the beginning and end of the process used here to introduce the intertwined and dynamic nature of scaffolding.

All of the transcripts also highlighted the **multi-domain** nature of scaffolding. This means that scaffolding included elements from the cognitive, metacognitive, motivational, and emotional domains. In the studied contexts, the scaffolding focused on the cognitive and metacognitive domains, through which the cognitive and metacognitive elements of reading comprehension strategy learning were supported and discussed (Gajria, Jitendra, Sood, & Sacks, 2007; Kinnunen & Vauras, 2010; Palincsar, 1986; Pressley, 2005). Scaffolding in the motivational and emotional domains was observed when the teacher supported the students' basic psychological needs for autonomy ("You can yourself decide what kind of detective you want to draw."), belongingness ("It is very nice that we can practice reading comprehension together."), and competence ("And I'm sure you will remember.") (cf. Stroet, Opdenakker, & Minnaert, 2013; Turner, Christensen, Kackar-Cam, Trucano, & Fulmer, 2014; Vansteenkiste & Ryan, 2013). Students' motivational tendencies were revealed when they actively contributed to the interactions by sharing their earlier experiences and drawing enthusiastically. The multi-domain nature of scaffolding should be carefully taken into account when the goal is to deepen our understanding of the scaffolding of complex skills, such as the listening and reading comprehension skills and the mathematical problem solving of low achievers focused on in this dissertation (De Corte, Depaepe, Op't Eynde, & Verschaffel, 2011; Guthrie & Klauda, 2014; Lehtinen, Vauras, Salonen, Olkinuora, & Kinnunen, 1995; Meyer & Turner, 2002; Vauras et al., 2009).

1.1. Scrutinizing the calibration of scaffolding

Recent developments in scaffolding research and all transcripts in the Introduction stress that teachers' scaffolding and students' learning should be scrutinized as intertwined, dynamic, and multi-domain long-term processes (Gresalfi, Barnes, & Cross, 2012; Van de Pol, Volman, Oort, & Beishuizen, 2015; Van Vondel, Steenbeek, Van Dijk, & Van Geert, 2016). However, scaffolding research has traditionally concentrated on teachers' short-term support (Van de Pol et al., 2010) and has not scrutinized the calibration of support for students' learning over the long-term processes. To deepen the understanding of the calibration of scaffolding, systematical empirical studies of the intertwined, dynamic, and multi-domain nature of teachers' scaffolding and students' learning during long-term goal-directed interactions are urgently needed. It is essential to pay attention to the opportunities created and taken

up during interactions by both students and teachers to unveil students' readiness for challenges and teachers' flexibility in calibrating scaffolding to students' needs (Berliner, 2001; Hayden, Rundell, & Smyntek-Gworek, 2013; Salonen, Vauras, & Efklides, 2005; Van de Pol et al., 2014; Van Geert & Steenbeek, 2005). Fine-grained analyses of scaffolding dynamics between students and teachers are crucial for deepening our understanding of the development of micro-level interactions into long-term interaction patterns at the meso- and macro-levels (Hollenstein, 2013; Praetorius et al., 2014; Steenbeek et al., 2012).

Scaffolding has sometimes been used too broadly as a synonym for any kind of support for students' learning (Puntambekar & Hübscher, 2005). Here, it is important to remember that already the seminal work on scaffolding emphasized the calibration of support for students' learning (Stone, 1998; Wood et al., 1976). In keeping with this emphasis, this dissertation scrutinizes how carefully teachers' support is calibrated to students' learning during extended goal-directed processes. The calibration of support from the learning environment is also included such that all three interventions conducted in this dissertation were carefully designed to be calibrated and continuously calibrated by the teachers to the needs of low achievers. During the design processes, the calibration of the learning environment was based on the recent theoretical understanding of the multi-domain support needed to achieve the target skills of the intervention, as well as our earlier experiences of implementing interventions together with teachers. The transcripts in the introduction demonstrate the role of the learning environment in the calibration process through, for example, the way in which the goals of the intervention environment created learning goals for the interaction. Furthermore, the role of the learning environment in the calibration process is highlighted by how the intervention provided the scaffolding context, for example tasks for the students to support their practicing and guidelines for the teachers to support their scaffolding.

Figure 1 introduces the students' learning, the teacher's support, and the support from the learning environment as intertwined elements of the scaffolding interactions. Wheels are used to illustrate these core elements to highlight that both teacher support and support from the learning environment must be dynamically calibrated to the students' learning during long-term scaffolding. On-going calibration is vital in proceeding towards the learning goals. If the calibration of the support fails, the achievement of the learning goals is threatened. This dissertation aims to deepen our understanding of these wheels and the dynamics of their calibration processes.
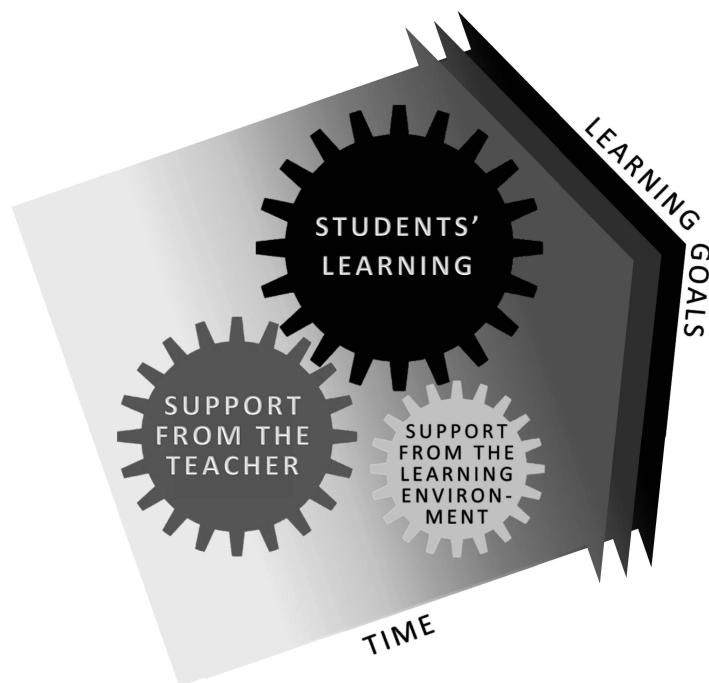
Figure 1. Core elements of scaffolding interactions and the dynamic calibration of support for students' learning

As Figure 1 shows, focusing on only one wheel narrows the perspective on scaffolding by failing to scrutinize calibration. In this dissertation, Study I focuses on students' learning, and Study IV focuses on teachers' support. In this way, Study I and IV represent traditional, but narrow perspectives on scaffolding. However, both studies aim to deeply understand the wheel they focus on during long-term goal-directed processes. Conducting an integrated and in-depth analysis of all, or at least two, wheels takes a wider perspective on scaffolding and helps to develop the understanding of the calibration processes involved in long-term scaffolding interactions. Studies II and III represent this kind of wide and deep perspective on scaffolding by integrating students' learning, teachers' scaffolding, and the dynamics of these wheels' calibration processes. The calibration of support from the learning environment is included in all studies because interventions are always a vital context in the scrutiny of wheels and their calibrations.

To deepen our understanding of the calibration processes involved in scaffolding interactions, this dissertation develops a theoretical optimal scaffolding model and related methods for the in-depth analysis of students' learning, scaffolding interactions, and teachers' scaffolding. The developed methods are used to scrutinize the contributions and calibrations of the contributions of the teachers and the low achievers over the course of long-term interventions designed in research projects of which this dissertation is a part. The empirical findings are discussed in order to theoretically deepen our understanding of the intertwined, dynamic, and multi-domain nature of

scaffolding and to provide evidence-based ways of increasing the quality of scaffolding practices. In this way, this dissertation addresses calls for the development of conceptualizations, analyses, and practices of scaffolding (Van de Pol et al., 2010).

1.1.1. Intertwined and dynamic nature of scaffolding

To scrutinize the calibration of teachers' scaffolding and students' learning during extended processes, a theoretical integrated model of optimal scaffolding process in the cognitive–metacognitive domain was constructed (Kajamies, Vauras, Kinnunen, Lehtinen, & Volet, in review). The adjective 'optimal' was added before 'scaffolding' to emphasize that scaffolding is of the highest quality when support is carefully calibrated to students' learning. Figure 2 describes the key components of the optimal scaffolding model through a snapshot of the intertwined and dynamic scaffolding process. As Figure 2 shows, the structure of the model is based on three interaction zones: opportunities created by the teacher, matches, and opportunities created by the students.
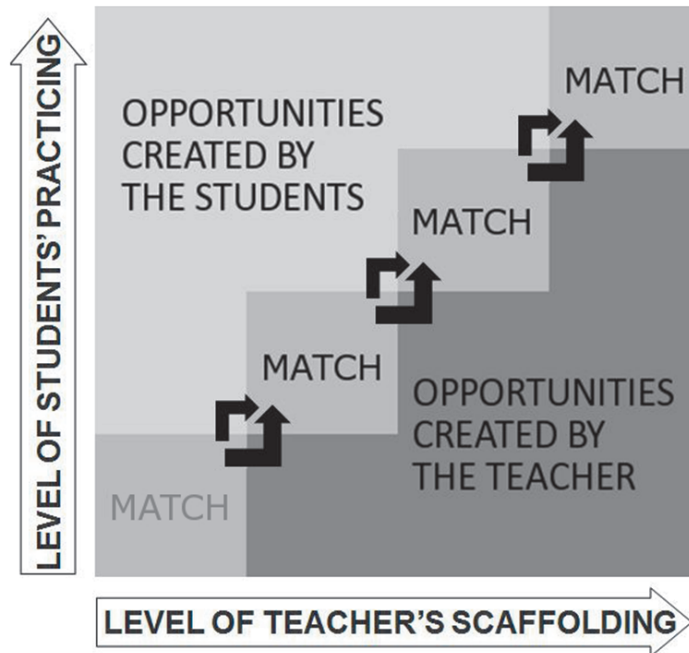
Figure 2. Intertwined and dynamic nature of the optimal scaffolding model (Kajamies et al., in review)

In **opportunities created by the teacher**, the level of the teacher's participation is higher than that of students' participation. The aim of these opportunities is to achieve a match between teacher and students participation at that higher level (Salonen et al., 2005; Steenbeek et al., 2012). Opportunities created by the teacher demonstrate that the teacher takes seriously her or his responsibility of systematically creating challenges for students' learning towards learning goals (Bransford, Darling-Hammond, & LePage,

2005; Lin et al., 2015; Maloch & Beutel, 2010; Turner et al., 2014; Wells & Mejía Arauz, 2006). If the students take up the opportunities created by the teacher by responding at the teacher's level, a **match** is achieved. When the match is achieved repeatedly (i.e., students exhibit sufficiently stable skills at the higher level), a teacher practicing optimal scaffolding will contingently **fade** the scaffolding at the higher level, thus gradually increasing the students' responsibility at that level (cf. key components of scaffolding by Van de Pol et al., 2010). Then, at a still higher level, the teacher will again create opportunities to **strengthen** the scaffolding of more advanced skills. Fading scaffolding at a lower level where students have demonstrated learning reveals a teacher's sensitivity to notice and interpret critical incidents and meaningful patterns of students' learning (Hayden et al., 2013; Myhill & Warren, 2005; Salonen et al., 2005; Schäfer & Seidel, 2015). Strengthening scaffolding at a higher level also reveals a teacher's flexibility in adapting scaffolding to students' learning needs within their zones of proximal development (Berliner, 2001; Muhonen et al., 2016; Rodgers, D'Agostino, Harmey, Kelly, & Brownfield, 2016; Salonen et al., 2005; Vygotsky, 1978).

In **opportunities created by the students**, the students' participation is higher than the teacher's participation. Opportunities created by students demonstrate that the students have taken on active roles in co-constructing understanding and are ready for higher-level challenges than those currently created by the teacher (Fredricks, 2014; Fulmer & Turner, 2014; Gresalfi et al., 2012; Reeve & Tseng, 2011; Van Vondel et al., 2016). A teacher who scaffolds in an optimal way will take up opportunities created by the students by beginning to participate at the higher level to match the students' participation. In this way, opportunities created by the teacher, matches, and opportunities created by the students are all dynamically intertwined zones of scaffolding interactions and are crucial in describing the quality of these interactions.

The goal of the optimal scaffolding model is to move the focus from the teacher to the dynamic interactions between teacher and students. When scaffolding interactions become fundamental, both matches and opportunities are vital, since continuous development towards the learning goals can be achieved through an **effective balance of matches and opportunities** (Salonen et al., 2005; Schweinle, Meyer, & Turner, 2006; Steenbeek et al., 2012). Matches are essential because they show that interaction participants can take up opportunities created by other participants. Matches also allow students to consolidate the skills they have already learned. Opportunities created by both teacher and students are pivotal in continuously pushing interactions towards qualitatively higher levels. Traditionally, scaffolding research has emphasized opportunities created by the teacher. However, the optimal scaffolding model also highlights opportunities created by the students and the take up of opportunities by both students and teacher during long-term processes. It is essential to examine how the teacher and the students reciprocally create opportunities for one another to participate at particular levels and to take up opportunities created to deepen understanding of the dynamic interplay between opportunities created and taken up (cf.

Engeström & Sannino, 2012; Gresalfi et al., 2012). Only if opportunities created are taken up at least eventually during long-term interactions, they grow into something that is shared among the interaction participants.

When scrutinizing the **long-term dynamics of scaffolding interactions**, the optimal scaffolding model emphasizes that if a teacher takes increasing responsibility for scaffolding during long-term processes, opportunities created by the teacher increase. By contrast, if students show increasing readiness for higher-level challenges, opportunities created by the students increase. If both teacher and students take up the opportunities that have been created, high-level matches increase and low-level matches decrease, resulting in optimal scaffolding interactions. When high-level matches increase, opportunities that are not taken up remain stable or even decrease over the course of the extended scaffolding processes. Otherwise, opportunities that are not taken up increase, assuming that the opportunity creator continues to create them despite the other participant's failure to take them up. To deepen our understanding of the formation and maintenance of optimal and non-optimal scaffolding interactions, we need to observe the long-term dynamics of opportunities and matches.

Despite the dynamic nature of interactions, it has been observed that interaction processes tend to stabilize through a subset of all possible interaction patterns (Kunnen & Van Geert, 2012). Within the dynamic systems approach, these recurrent patterns are called **attractors**, while patterns that never or rarely occur are called **repellors** (Hollenstein, 2013). As Hollenstein (2013) and Kunnen and Van Geert (2012) emphasize, entering an attractor requires very little energy from the interaction participants, but escaping it requires much more. This makes this kind of interaction more typical than other possible interactions. By contrast, entering a repellor demands a great deal of energy from the interaction participants, but escaping it requires very little, which makes this kind of interaction more rare than other possible interactions. Complex interactions can have many attractors and repellors of varying strengths (Kunnen & Van Geert, 2012). The optimal scaffolding model presupposes that attractors can exist at low levels at the beginning of interactions, but that they should move to higher levels towards learning goals during long-term interactions. Stability can be caused by the interplay of strong attractors and repellors, which can lock interactions into non-optimal levels (Hollenstein 2013; Turner et al., 2014), since opportunities that are inconsistent with attractors have only minimal and temporary impacts (Vallacher, Van Geert, & Nowak, 2015).

Optimal scaffolding, as a deeply intertwined and dynamic process involving attractors and repellors, calls for the application of dynamic system methods to scrutinize the variability and stability of matches and opportunities at different levels over extended scaffolding processes. This dissertation uses these methods to capture educationally meaningful interaction patterns of opportunities created and taken up in the cognitive–metacognitive domain to deepen understanding of scaffolding processes and their learning outcomes.

1.1.2. Multi-domain nature of scaffolding

Students' deep productive disciplinary engagement is a crucial goal in the scaffolding of complex skills (Engle 2012; Fredricks, Blumenfeld, & Paris, 2004; Hart, Stewart, & Jimerson, 2011; Turner et al., 2014). To achieve deep productive disciplinary engagement, **scaffolding in cognitive, metacognitive, motivational, and emotional domains is needed** (Salonen, Lepola, & Vauras, 2007; Stroet et al., 2013; Turner, 2010). However, traditionally, scaffolding research has focused on only one domain of scaffolding, typically scaffolding in the cognitive domain (Van de Pol et al., 2010) or the motivational domain (Stroet et al., 2013; Turner et al., 2014). Because multi-domain implementations and analyses of scaffolding are rare, an important goal of this dissertation is to study scaffolding and learning in the cognitive, metacognitive, motivational, and emotional domains. For the sake of simplicity, this dissertation groups these four domains into two main domains: cognitive–metacognitive and motivational–emotional. Figure 3 captures these domains and the respective elements of interest in this dissertation.
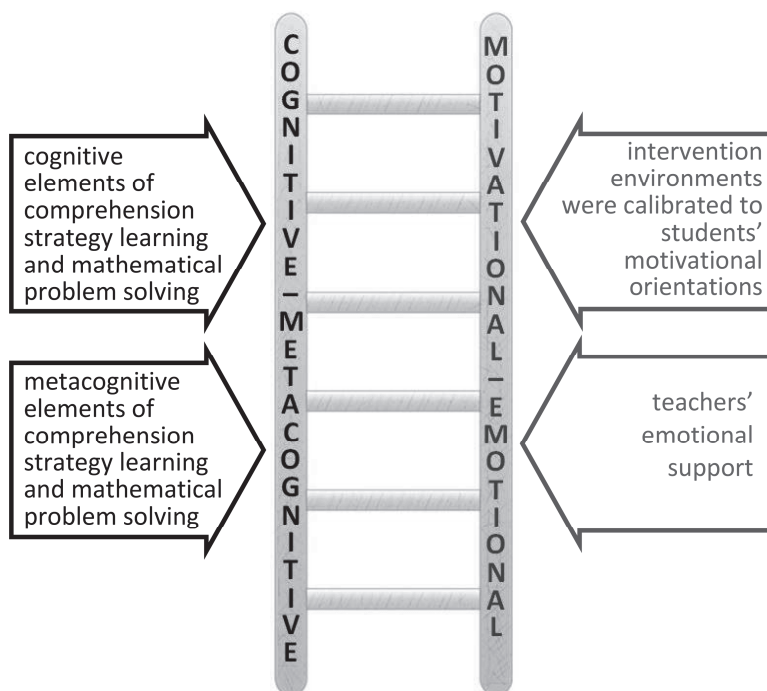
Figure 3[3]. Domains of scaffolding and learning in this dissertation

The emphasis in this dissertation is on the cognitive–metacognitive domain of teachers' scaffolding and students' learning. In other words, this dissertation examines

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[3]Figure 3 uses a ladder, Figure 4 uses a building, and Figure 5 uses a scaffold from the construction field as metaphors, since the word 'scaffolding' originates from the word 'scaffold', which is a temporary platform used to support building construction work at heights above the ground.

the cognitive and metacognitive elements of comprehension strategy learning (Gajria et al., 2007; Kinnunen & Vauras, 2010; Palincsar, 1986; Pressley, 2005) and mathematical problem solving (De Corte, Depaepe, Op't Eynde, & Verschaffel, 2011; Greer, Verschaffel, Van Dooren, & Mukhopadhyay, 2009; Verschaffel, Greer, & De Corte, 2000). However, the motivational–emotional domain of teachers' scaffolding and students' learning is also considered to be vital. The motivational–emotional domain is explored in this dissertation from the students' perspective, such that students' motivational orientations (Vauras et al., 2009) are evaluated and reported as a part of their background information. The motivational orientations of the intervention students are also carefully taken into account when designing the intervention environments, which are calibrated to students' specific motivational–emotional needs. Furthermore, in Study IV, the motivational–emotional domain is scrutinized from the perspective of the teachers' emotional support.

Earlier studies have shown the benefits of multi-domain scaffolding while supporting complex skills, such as listening and reading comprehension strategies (Guthrie & Klauda, 2014; Kajamies, Mattinen, Räsänen, Hannula-Sormunen, & Lehtinen, 2014; Lehtinen et al., 1995; Mol, Bus, De Jong, & Smeets, 2008; Ng, Bartlett, Chester, & Kersland, 2013; Pressley, 2005) and mathematical problem solving skills (De Corte et al., 2011; Pongsakdi et al., 2016; Verschaffel et al., 2000). This dissertation focuses on the contexts of such multi-domain scaffolding. While scaffolding students' learning of cognitive comprehension or problem solving strategies, it is critical to find ways to also support students' metacognition, motivation and emotions to achieve their deep productive engagement in listening and reading comprehension and mathematical word problem solving (Greer et al., 2009; Guthrie, Wigfield, & You, 2012; Lehtinen et al., 1995; Meichenbaum & Biemiller, 1998; Meyer & Turner, 2002; Vauras et al., 2009).

Transcript 4 from our reading comprehension interventions empirically illustrates this kind of scaffolding interaction, in which both the cognitive–metacognitive and the motivational–emotional domains are integrated. The shortened Transcript 4 is drawn from the eighth lesson, during which the teacher's (Eeva's) goal was to scaffold low achievers (Kalle, Lasse, and Mikko) in understanding the benefits of applying the main idea selection strategy in other reading comprehension contexts after they had practiced selecting main ideas with different tasks.

> Eeva: What benefits would you get if you find the main ideas from your science book and study just those main ideas?
> Kalle: In the exams.
> Eeva: How would it help you if you only study the main ideas?
> Lasse: They are important.
> Eeva: Yes! How would it help you?
> Mikko: If you have read also unimportant things, then if you have a little bit of a same kind of a question in the exams, then you start to think, does it apply to this question or somewhere else.

Eeva: You mean that the unimportant things disturb you.
Kalle: They will be confusing.
Eeva: The unimportant things confuse you.
Kalle: The wrong ideas go upon the right ideas.
Mikko: Then you will forget the right ideas.
Eeva: Good! What else?
Lasse: I can't think of any more.
Eeva: How much do you have to study if you select only the main ideas?
Mikko: A lot less because if you read carefully also the unimportant things, it would take a lot longer.
Eeva: You don't have to keep in your mind the unimportant things. You can learn faster. You don't have to read so much. So now, here, you have a thing that helps you to make studying easier. You don't have to study those side issues so carefully. If you are reading, for example, a science book, then you concentrate on the main ideas. You read carefully those ideas that are important for you. They are easier to remember when you have less of them. If you study unimportant issues, you make unnecessary work.

The group continues practicing the selection of main ideas from texts.

As Transcript 4 demonstrates, the teacher persists in calibrating her cognitive–metacognitive scaffolding to support the students' understanding of the benefits of applying the main idea selection strategy to other reading comprehension contexts. Transcript 4 also shows how students construct new understandings together and achieve goals beyond what would be possible through their unsupported efforts. Furthermore, Transcript 4 highlights the crucial importance of this kind of interaction for low achievers' deep disciplinary engagement in reading comprehension practice. When the students understand the benefits of practicing reading comprehension strategies for themselves, the motivation to persist in practicing complex tasks should increase. Furthermore, the positive feedback given by the teacher during Transcript 4 is considered to be crucial motivational–emotional scaffolding for the students' deep engagement.

In Study IV, when the motivational–emotional domain was scrutinized from the perspective of preschool teachers' emotional support, self-determination theories were used as a theoretical foundation. According to self-determination theories, teachers' scaffolding in the motivational–emotional domain includes support for students' **basic psychological needs for autonomy, belongingness, and competence** (cf. Stroet et al., 2013; Turner et al., 2014; Vansteenkiste & Ryan, 2013). If students' basic psychological needs are not supported, scaffolding may not be optimal and yield expected outcomes. Neglecting explicit and systematical scaffolding in the motivational–emotional domain can be particularly harmful for low achievers' learning of complex skills (De Corte et al., 2011; Harme & Pianta, 2005; Quirk & Schwanenflugel, 2004; Roorda, Koomen, Spilt, & Oort, 2011; Schweinle, Turner, & Meyer, 2008; Silinskas et al., 2016). Study IV focuses, in particular, on the the nature and evolution of preschool teachers' scaffolding in the emotional domain, since consistent positive emotional support is especially crucial for

children's learning and well-being (Brock & Curby, 2014; Gregory & Korth, 2016; Kiuru et al., 2016; Salminen et al., 2012).

1.2. Challenges of optimal scaffolding

Optimal scaffolding is rare in teacher-student interactions (Mercer & Dawes, 2014; Palincsar, 1986; Stone, 1998; Van de Pol et al., 2014). If teachers must simultaneously adapt to the needs of many individuals during dynamic interactions, which is typical in large classrooms, optimal scaffolding is particularly challenging (Calder, 2015; Rodgers et al., 2016; Smit & Van Eerde, 2013). Teachers tend to struggle in their roles as sensitive and flexible facilitators (Nathan & Kim, 2009; Salonen et al., 2005), and students are typically not used to being positioned as active participants in co-constructing understanding (Fredricks, 2014; Fulmer & Turner, 2014; Gresalfi et al., 2012; Reeve & Tseng, 2011; Van Vondel et al., 2016). Teacher domination and low-level teacher initiation–student reply–teacher evaluation sequences are typical non-optimal attractors observed in earlier teacher–student interaction research (Hamre et al., 2013; Hedin & Gaffney, 2013; Howe & Abedin, 2013; Mehan, 1998; Muhonen et al., 2016; Pianta & Hamre, 2009). However, to scaffold high-level learning, teachers should allow space for students' contributions by, for example, asking open questions demanding high-level thinking, and instead of evaluating, encourage justifications, elaborations, and syntheses of information (Gillies, 2016; Mercer & Dawes, 2014; Muhonen et al., 2016; Wells & Mejía Arauz, 2006), which typically remain repellors in teacher–student interactions.

Teachers often struggle to **diagnose students' learning dynamics** with sufficient depth and accuracy to adapt scaffolding to their individual needs (Chi, Siler, & Jeong, 2004; Herppich, Wittwer, Nückles, & Renkl, 2013; Palincsar, 1986; Van de Pol, Volman, & Beishuizen, 2011). Teachers' diagnostic skills are especially important for identifying those low achievers who have difficulties achieving the current learning goals without optimal scaffolding. When low achievers are identified, diagnostic skills are needed to follow up on the students' intra- and inter-individual variability in terms of the dynamics of their learning of the relevant subskills during scaffolding (Flynn & Siegler, 2007; Kunnen & Van Geert, 2012). As described earlier, continuous observation of opportunities created by students and matches also reveals important aspects of students' learning dynamics. In addition to these kinds of continuous observations, parallel tests, which are designed for the repeated evaluation of students' learning, can also be useful in diagnosing learning dynamics during long-term scaffolding. Collecting intensive longitudinal and time series data can deepen our understanding of the effectiveness of scaffolding and support evidence-based decisions regarding how to face the challenges of scaffolding by increasing its optimality (Gates & Liu, 2016; Kromrey & Foster-Johnson, 1996; Robey, Schultz, Crawford, & Sinner, 1999; Swansson, 1999).

Since researchers have faced many challenges and encountered only some success when trying to support teachers in optimal scaffolding (Rodgers et al., 2016; Turner et al., 2014; Van de Pol et al., 2015), this dissertation provided carefully designed multi-domain learning environments and **professional development programs** for the teachers who implemented the interventions. Expert lectures and counselling were used to help the teachers apply theoretical principles in complex real-life scaffolding practices. Purposefully selected video clips of interactions during the interventions were confidentially used in counselling sessions to create opportunities to collaboratively scrutinize and reflect on the relevant aspects of scaffolding practices in each intervention group (cf. Borko, Jacobs, Seago, & Mangram, 2014; Pehmer, Gröschner, & Seidel, 2015). An important goal in these video-based discussions was to scaffold the teachers' skills in noticing and interpreting critical incidents and meaningful patterns of interactions and students' learning (Schäfer & Seidel, 2015). Another goal was to increase the teachers' sensitivity and flexibility in continuous decision making based on opportunities created by the students to support progress towards optimal scaffolding in future interactions.

1.3. Reasons to focus on scaffolding low achievers' learning

The scaffolding of the low achievers' learning was chosen as the empirical focus of this dissertation because it is vital to develop optimal scaffolding of these **at-risk** children's learning (Gresalfi, 2009; Van de Pol & Elbers, 2013; Vauras et al., 2009). Without optimal scaffolding, low achievers are at risk of facing significant difficulties during their educational and employment careers and in terms of their life satisfaction (Fuchs, Geary, Fuchs, Compton, & Hamlett, 2016; Hakkarainen, Holopainen, & Savolainen, 2016; Mazzotti & Mustian, 2013). Earlier studies have revealed that **teachers face challenges** especially in the optimal scaffolding of low achievers' learning (Mercer & Dawes, 2014; Palincsar, 1986; Stone, 1998; Van de Pol et al., 2014). Teachers typically diagnose high and average achievers more accurately and scaffold them more optimally than they do low achievers (Begeny, Krouse, Brown, & Mann, 2011; Hurwitz, Elliott, & Braden, 2007; Kupers, Van Dijk, & Van Geert, 2015; Rodgers et al., 2016; Steenbeek et al., 2012; Südkamp, Kaiser, & Möller, 2012). Moreover, there is a danger that teachers experience more negative affects and teaching-related stress when scaffolding low achievers than high achievers (Nurmi, 2012; Silinskas et al., 2016). These inequities, which result in high and average achievers receiving more optimal scaffolding than low achievers, further highlight the need to focus on studying and developing the optimal scaffolding of low achievers' learning.

Interventions for low achievers have typically concentrated on scaffolding their **basic** decoding skills in reading and calculation skills in mathematics. These skills are essential, but it is not sufficient to optimally scaffold low achievers solely in their basic decoding skills in reading (Crosnoe et al., 2010; Gough & Tunmer, 1986; Kim, 2015; Paris,

Carpenter, Paris, & Hamilton, 2005; Taylor, Pressley, & Pearson, 2002; Tiffin-Richards & Schroeder, 2015) and their calculation skills in mathematics (Broza & Ben-David Kolikant, 2015; Fuchs, Fuchs, Compton, Hamlett, & Wang, 2015; Geary, 2004; Gersten & Chard, 1999; Verschaffel et al., 2000; Verschaffel, Luwel, Torbeyns, & Van Dooren, 2009). To respond to increasing learning demands at school and in later life, low achievers must also be optimally scaffolded in their **complex** listening and reading comprehension and mathematical problem solving skills (Haber et al., 2016; Meichenbaum & Biemiller, 1998; Roorda et al., 2011; Vauras, 1991). Particularly when low achievers have acquired good enough basic skills, the emphasis of scaffolding should proceed to more complex skills (Broza & Ben-David Kolikant, 2015; Language and Reading Research Consortium, 2015; Torppa et al., 2016). If low achievers are limited to practicing basic decoding and calculation skills, then they are given opportunities to acquire and consolidate only these basic skills. However, the optimal scaffolding of complex cognitive–metacognitive skills is needed to support low achievers in practicing and applying the complex comprehension and problem solving skills needed in real-life contexts (Gresalfi et al., 2012). Without the optimal scaffolding of these complex skills, there is a risk of long-term relative regress of low achievers' comprehension and problem solving skills (Lepola, Salonen, Vauras, & Poskiparta, 2004; Sideridis, 2011; Vauras, Kinnunen, & Kuusela, 1994). Based on these reasons for developing optimal scaffolding for low achievers' learning of complex skills, this dissertation focuses on scaffolding low achievers during comprehension and problem solving interventions.

Carefully designed and systematically implemented multi-domain interventions have produced average-level improvements in students' listening comprehension skills (Dickinson, Griffith, Golinkoff, & Hirsh-Pasek, 2012; John, 2009; Kajamies et al., 2014; Mol et al., 2008; Whitehurst & Lonigan, 1998), reading comprehension skills (Gajria et al., 2007; Guthrie & Klauda, 2014; Palincsar, 1986; Pressley, 2005; Solis et al., 2012; Suggate, 2016), and mathematical problem solving skills (Fuchs & Fuchs, 2005; Jitendra & Xin, 1997; Kroesbergen & Van Luit, 2003; Verschaffel & De Corte, 1997). However, earlier intervention studies scrutinizing the developmental differences among high, average and low achievers have typically shown that it is particularly challenging to develop the complex cognitive–metacognitive skills of the low achievers (Baxter, Woodward, Voorhies, & Wong, 2002; Lehtinen et al., 1995; Vauras, Rauhanummi, Kinnunen, & Lepola, 1999; Verschaffel & De Corte, 1997). Challenges in supporting low achievers' complex skills emphasize the need to deepen our understanding of the special aspects of low achievers' learning and evidence-based ways of increasing the quality of multi-domain scaffolding practices. This is particularly vital because low achievers' resistance has been linked to non-optimal scaffolding interactions, including mismatches between teachers' and students' contributions during scaffolding (Broza & Ben-David Kolikant, 2015; Roeser, Eccles, & Sameroff, 2000; Vauras, Salonen, & Kinnunen, 2008).

Low achievers' resistance to scaffolding attempts can also be reciprocally linked to low achievers' long-term, stabilized **motivational–emotional vulnerabilities and self-regulation difficulties** (Annevirta & Vauras, 2006; Lehtinen et al., 1995; Lepola, Lynch, Kiuru, Laakkonen, & Niemi, 2016; Meichenbaum & Biemiller, 1998). Especially in complex comprehension or problem solving tasks, low achievers typically lack task orientation and show motivational vulnerability in the form of ego-defensiveness or social dependence (Salonen, Lehtinen, & Olkinuora, 1998; Vauras et al., 2009). Low achievers' motivational–emotional vulnerability can be observed in learning situations as, for example, a lack of persistence, helplessness, substitute actions, or externalizing/internalizing problem behaviors. Some low achievers also show a lack of interest, inadequate beliefs, or negative emotions towards practicing with challenging tasks (García, Rodríguez, Betts, Areces, & González-Castro, 2016; Kloosterman, 2002; Ma, 1999; McLeod, 1992; Op't Eynde, De Corte, & Verschaffel, 2001; Schweinle et al., 2008; Silinskas et al., 2016). Low achievers can also be very sensitive to teachers' emotional support (Hamre & Pianta 2005). Self-regulation difficulties typically show up in complex comprehension or problem solving tasks, during which low achievers seldom use comprehension strategies to understand the task situations, monitor their understanding or solution processes, and evaluate their process outcomes (Bryant, Bryant, & Hammill, 2000; Carr & Biddlecomb, 1998; De Corte, Verschaffel, & Op't Eynde, 2000; Desoete, Roeyers, & Buysse, 2001; Gajria et al., 2007; Kinnunen & Vauras, 2010). This accumulation of cognitive–metacognitive and motivational–emotional difficulties among low achievers highlights that these domains should all be integrated in the study and development of the optimal scaffolding of low achievers.

Paying attention to scaffolding **as early as possible** is critical (Finnish National Board of Education, 2016), because delays in children's cognitive–motivational development can be reliably identified as early as the age of four (Lepola, Laitinen, & Kajamies, 2013; Lepola, Lynch, Laakkonen, Silvén, & Niemi, 2012; Valtonen, Ahonen, Lyytinen, & Lyytinen, 2004), and early preventive support is effective (Heckman, 2006; Karoly, Kilburn, & Cannon, 2005). Study IV in this dissertation focused on early prevention among four-year-old low achievers, whose preschool teachers implemented interventions to scaffold the children's listening comprehension skills, which are crucial for their daily interactions and which lay the foundation for future reading comprehension skills (Dufva, Niemi, & Voeten, 2001; Kim & Phillips, 2016; Lepola et al., 2016; Paris & Paris, 2003; Torppa et al., 2016). The interventions in Studies I through III focused on scaffolding ten-year-old low achievers' reading comprehension and mathematical word problem solving strategies, which are crucial but often not sufficiently supported skills for the life-time learning and application of reading and mathematical skills in real-life contexts (Guthrie & Klauda, 2014; Pressley, 2005; Verschaffel et al., 2009).

2. Aims and structure of the dissertation

As was shown in the introduction, theoretical definitions and empirical observations emphasize the intertwined nature of scaffolding by tightly combining the optimality of teachers' support with students' learning. Furthermore, the dynamic nature of scaffolding is highlighted through a focus on fading and strengthening as key elements of optimal scaffolding during long-term processes. Multi-domain scaffolding in carefully designed intervention environments and professional development programs for teachers are two highlighted solutions to the challenges of optimally scaffolding low achievers' learning. However, traditionally, scaffolding research has empirically concentrated only on teachers' short-term support and has not scrutinized the calibration of multi-domain support for students' learning dynamics during long-term processes. This means that earlier scaffolding research has not carefully scrutinized the intertwined, dynamic, and multi-domain nature of scaffolding. Based on these theoretical definitions, empirical challenges, and scaffolding research traditions, each of the four studies in this dissertation has both general and specific theoretical, methodological, empirical, and practical aims. All of these aims are described in Figure 4.

General Aims

Theoretical: Deepen understanding of scaffolding as intertwined, dynamic, and multi-domain interaction process

Methodological: Develop tools to systematically analyze and represent educationally meaningful learning, scaffolding interaction, and scaffolding dynamics over extended processes

Empirical: Study scaffolding from intertwined, dynamic, and multi-domain perspectives to examine the usefulness of analytical tools in understanding scaffolding practices and the effectiveness of scaffolding on low achievers' learning

Practical: Promote and explore professional development in optimal scaffolding by developing and identifying evidence-based best practices

Specific Aims

Study II
Establish the potential of the State Space Grids method to represent and analyze scaffolding interactions

Study III
Deepen understanding of the intertwined and dynamic nature of evolving optimal and non-optimal scaffolding patterns

Unpack the nature of cognitive–metacognitive scaffolding

Study I
Determine the effectiveness of cognitive–metacognitive and motivational–emotional scaffolding on low achievers' learning

Explore the nature of motivational–emotional scaffolding

Study IV
Gain insight to the nature and evolution of emotional scaffolding

Figure 4. Overview of the dissertation aims

To progress towards optimal scaffolding of low achievers' learning, scaffolding must be both theoretically and empirically scrutinized from intertwined, dynamic, and multi-domain perspectives. All four studies in this dissertation advance our understanding of scaffolding by combining either two (Studies I and IV) or all of the relevant perspectives (Studies II and III). As Figure 5 illustrates with bold landings, Studies I and IV combine dynamic and multi-domain perspectives, but leave out the intertwined perspective because the focus of the analysis is on either students' learning (Study I) or on teachers' scaffolding (Study IV). The intertwined perspective is introduced in Studies II and III, which scrutinize both students' learning and teachers' scaffolding. Study I opens the door to the construction site and constructs understanding on the first landing by determining the effectiveness of multi-domain scaffolding in addressing low achievers' learning dynamics. Studies II and III take the next steps on the second landing by combining all perspectives to unpack the nature of cognitive–metacognitive scaffolding with new methodological solutions to analyze evolving scaffolding patterns. Study IV continues on the third landing by exploring the dynamics of motivational–emotional scaffolding.
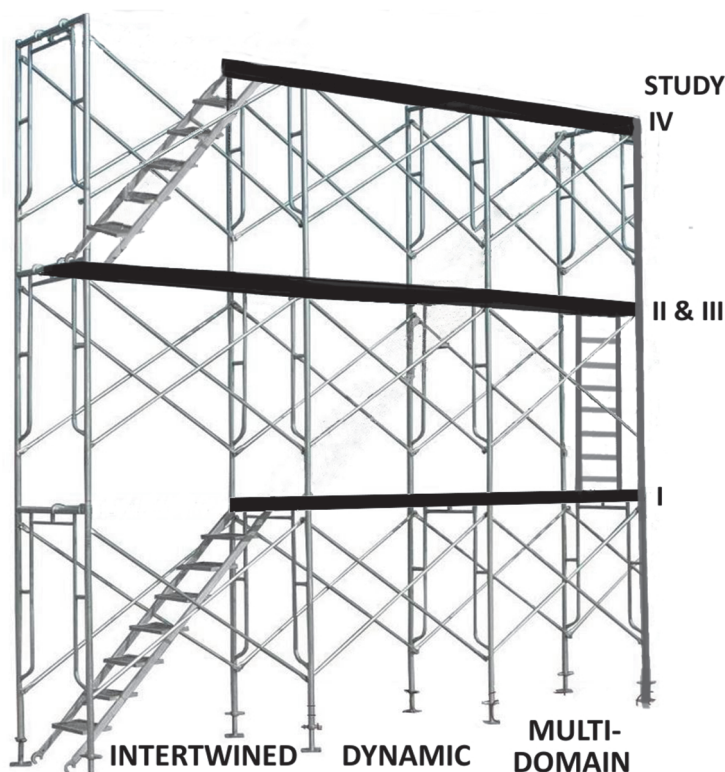
Figure 5. Overview of the perspectives combined in each study

3. Methods

This dissertation comprises of four intervention studies for low achievers. All studies used a longitudinal mixed methods approach that combined quantitative and qualitative data collection and analytical methods in order to always select the best methods available to answer the current research questions (Creswell, 2014; Teddlie & Tashakkori, 2010). Methods utilized included carefully designed tests, quasi-experimental and single-subject designs, and in-depth case studies with systematic interaction video observations to facilitate a deep understanding of scaffolding and learning dynamics during long-term interventions.

3.1. Participants

Table 1 presents a summary of the participants in this dissertation.

Table 1. Participants

Study I	Study II	Study III	Study IV
Original sample of participants			
Ten-year-old fourth grade students (n = 438), their classroom teachers (n = 21), and special education teachers (n = 11) from the *Quest for Meaning* project[4]			Four-year-old low achievers (n = 170) and their preschool teachers (n = 21) from the *Bunny Stories* project[5]
Selected participants for interventions			
Students were selected based on their low-achievement in skills practiced in the interventions			
8 low achievers in word problem solving were scaffolded during the interventions by a researcher	57 low achievers in reading comprehension were scaffolded during the interventions by 11 special education teachers		46 low achievers in listening comprehension were scaffolded during the interventions by 21 preschool teachers
Selected participants for in-depth observation studies			
Development of intervention (n = 8), control (n = 16), and comparison students (n = 405) was studied	Methodological illustrations were produced from systematic video observations of		
	teacher Anna and 3 low achievers (group A)	teacher Anna and 3 low achievers (group A) + teacher Eeva and 3 low achievers (group E)	two teachers, Petra and Leena
Quasi-experimental and single-subject designs were used	3 lessons from beginning, middle, and end of the intervention were analyzed (total duration 1 hour and 27 minutes)	19 lessons/group from long-term intervention process were analyzed (total duration 22 hours)	3 sessions from beginning, middle, and end of the intervention were analyzed (total duration 2 hours and 50 minutes)

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[4]The project was funded by Grant No. 47369 from the Council of Cultural and Social Science Research, the Academy of Finland, awarded to Professor Marja Vauras.
[5]The project was funded by Grant No. C224 from Finland's Slot Machine Association, awarded to Niilo Mäki Institute/Project Leader Aino Mattinen.

As can be seen in Table 1, the participants included both students and teachers[6]. Promoting and exploring teachers' professional development in optimal scaffolding was seen as a promising way to improve scaffolding also in the future by developing and identifying evidence-based best practices. A productive starting point for collaboration was laid by asking special education teachers and day care professionals from Southern Finland to volunteer if they were interested in expanding their expertise in scaffolding comprehension skills. The school principals, day care directors, teachers, and preschool teachers all signed collaboration contracts. Intervention teachers agreed to videotape their intervention sessions and gave written concent for the use of the videos for their professional development. The guardians gave their written consent for their children's participation. The guardians of the intervention children also gave their written consent for their children's participation in the intervention, the videotaping, and the use of the videos for the teachers' professional development. Classroom teachers and preschool teachers were interviewed about their typical practices in supporting the interventions' target skills. The names of all participants have been changed for reporting to preserve anonymity. In all respects, ethical codes for scientific research were followed according to the guidelines of the ethical committee of the Academy of Finland and the University of Turku.

Children were selected for the interventions based on their low achievement compared to their grade or age level in the focal skills. This kind of selection criteria has also been used in earlier studies (Mazzotti & Mustian, 2013; Proctor & Prevatt, 2003). Grade/age-level discrepancies were seen as the most adequate way to select the children who would benefit the most from the interventions. The selection criteria were in line with the guidelines of the Finnish National Board of Education (2016) emphasizing equal opportunities for everyone to receive educational services in accordance with their special needs. Grade/age-level discrepancies were used even though the traditional emphasis in the field of learning disabilities has been severe discrepancies between intelligence and specific achievement (Hammill, 1990; Mazzotti & Mustian, 2013) because intelligence does not predict response to intervention (Büttner & Hasselhorn, 2011; Niemi et al., 2011; Vellutino et al., 1996).

In **Study I**, those students who received low pre-test scores in word problem solving (cumulative 32%, n = 138) were selected from the total sample. For practical reasons, the intervention students, four boys and four girls, were selected from these low achievers from two classes (n = 16). Pairwise-matched same-sex controls were selected from the remaining low achievers (n = 130) on the basis of their scores in word

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[6]For the sake of simplicity, term 'teacher' is used as a main concept for the special education teachers and preschool teachers who implemented the studies. Similarly, the term 'student' is used as a main concept for all children who participated in the studies, even though the participants in Study IV were still in day care in the Finnish context.

problem solving, task orientation, arithmetical skills, and nonverbal intelligence. Two control students were selected for each intervention student. Half of the control students did not get any special attention during the intervention (control), while the other half took part in a reading comprehension (rc) intervention that was carried out by the teachers and analyzed in depth in Studies II and III (rc-control). The matching was successful because the only difference among intervention, control, and rc-control students was found in reading comprehension, such that rc-control students performed more poorly than control students. The multi-domain nature of low achievement showed up when other students had higher scores in word problem solving, task orientation, arithmetical skills, and reading comprehension than the intervention, control, and rc-control students. The background information of the intervention students demonstrated that they were seldom task-oriented in classrooms.

In **Studies II and III**, the special education teachers Anna and Eeva and their groups were selected for in-depth observations, because they, among the total sample of 11 teachers, exhibited the scaffolding variation noticed during the intervention. Anna had worked for many years as a special education teacher focusing primarily on decoding, writing, and speech therapy, while Eeva had worked for many years as a classroom teacher and had just started as a special education teacher. The background information of the six low achievers in Anna's and Eeva's groups demonstrated that all student were low achievers in reading comprehension. Furthermore, four also had difficulties with decoding. The students' motivational vulnerability manifested in the classrooms, since none of the intervention students but one were task-oriented and three were socially dependent and/or ego-defensive.

In **Study IV**, low achievers were selected on the basis of their preschool teachers' evaluations that they would benefit from scaffolding in listening comprehension. Based on the careful testing of vocabulary, morphology, and comprehension skills, 46 low achievers were selected for the intervention group, and 46 pairwise-matched controls were selected for the control group. The tests are not described in detail, since the focus was on the teachers' scaffolding skills. The preschool teachers Petra and Leena were selected on the basis of differences in their scaffolding noticed during the intervention. Both preschool teachers had worked in day care for many years.

3.2. Evaluating students' skills and motivational orientations

Before the interventions in **Studies I through III**, the students' skills and motivational orientations were evaluated to collect background information on the 4th graders' typical skill levels and the low achievers' difficulties. With careful multi-domain testing, the goal was to select the students who needed and would benefit from the interventions the most. When standardized tests were not available, necessary tests and scales were developed based on earlier research as part of this dissertation. The tests

and scales used are described briefly in the following paragraphs. More information can be found in the original publications.

Classroom teachers evaluated the students' **motivational orientations** in typical classroom situations using a Likert scale (Vauras, Salonen, & Kajamies, 2017). Based on confirmatory factor analysis results, a mean score for each orientation was used to indicate each student's task orientation, social dependence, and ego-defensive externalizing and internalizing orientations. In Study I, only task orientation was used, and in Studies II and III, all orientations were used.

Reading comprehension was evaluated using the Finnish standardized reading test ALLU (Lindeman, 1998). The task was to answer 48 multiple-choice questions about the four texts read. The total number of correct answers was used to classify the students into reading comprehension skill groups.

In **Study I**, students' word problem solving skills, arithmetical skills, and nonverbal intelligence were also evaluated.

Word problem solving was evaluated with 15 one-step and multi-step problems that demanded acute realistic consideration, not only the straightforward application of arithmetical operations (Kajamies, Vauras, Kinnunen, & Iiskala, 2003). The total number of points from the calculation steps and answers was used as a main indication of a student's word problem solving skills.

Arithmetical skills were evaluated with a time-limited RMAT test (Räsänen, 2004). The total number of correct solutions in the RMAT was used as an indication of a student's arithmetical skills.

Non-verbal intelligence was evaluated with Standard progressive matrices (Raven, Raven, & Court, 2000). The total number of correct choices was used as an indication of a student's non-verbal intelligence.

In **Studies II and III**, students' decoding and reading comprehension were also evaluated.

Decoding was tested using the Finnish standardized reading test ALLU (Lindeman, 1998). The task was to separate words from word chains within a limited time. The total number of correct answers was used to classify the students into decoding skill groups.

Reading comprehension was also tested using a demanding task, including a text with open questions and cloze tasks (Vauras, Kajamies, & Kinnunen, 2017). The students'

answers were evaluated on the basis of the depth of their understanding of the text and their inference-making skills. A sum score of the open questions and the cloze tasks was used to indicate reading comprehension skills.

3.3. Intervention contexts

Small-group interventions were used as contexts to study scaffolding because low achievers can be more optimally scaffolded in smaller groups than in larger groups (Blatchford, Bassett, & Brown, 2011; Van de Pol & Elbers, 2013). Challenges in supporting low achievers' learning were addressed through the development of interventions designed to combine optimal teacher scaffolding with innovative learning environments. Following the optimal scaffolding model (Kajamies et al., in review), the goal of the interventions was to optimally scaffold low achievers' learning with frequent and strong opportunities created by the teacher, dynamic matches between the teacher's and the low achievers' participation, and the taking up of opportunities created by the low achievers. Interventions focused on multi-domain scaffolding for situations involving both the cognitive–metacognitive and the motivational–emotional domains needed in learning the focused skills. During the instructional discussions, the low achievers were scaffolded to become active, strategic, and motivated learners through questioning, feedback and modelling. If the low achievers showed increasing mastery, the teacher was supposed to fade out her scaffolding and encourage the low achievers to take more responsibility. Innovative learning environments were used to help the low achievers become deeply engaged in learning and interactions. Figure 6 presents an overview of the intervention contexts in this dissertation.

Study I

Scaffolding mathematical problem solving with computer-supported adventure game

Study II-IV

Scaffolding reading and listening comprehension skills with dialogic reading in adventure story environments

Professional development programs provided to support teachers in optimal scaffolding
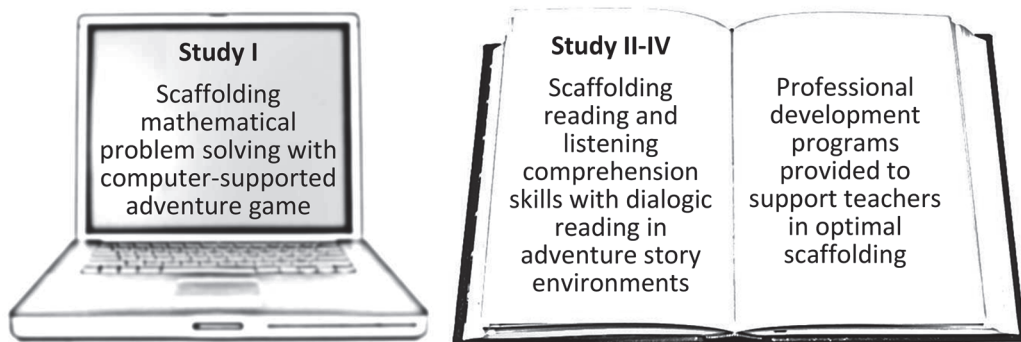
Figure 6. Intervention contexts

All intervention interactions were videotaped, since videos are powerful tools for capturing scaffolding interactions during developmental processes (Derry et al., 2010; Van de Pol et al., 2010). Furthermore, selected video clips were used in professional development programs to collaboratively scrutinize and reflect on relevant aspects of scaffolding practices in each intervention group (cf. Borko et al., 2014; Pehmer et al., 2015).

In **Studies I through III**, the students followed the mainstream curriculum of Finnish general education, including teaching in reading and mathematics. However, the analysis of the classroom teachers' interview answers showed that explicit teaching of reading comprehension or mathematical problem solving strategies was rare. This means that the interventions focused on skills that were typically not taught explicitly in classrooms. In **Study IV**, the children followed the mainstream curriculum of Finnish early childhood education, including story reading. However, the analysis of preschool teachers' interview answers showed that dialogic reading was rare. This suggests that stories were read more interactively in the interventions than they typically are in day care.

3.3.1. Scaffolding problem solving with computer-supported adventure game

In **Study I**, we designed an intervention to develop mathematical word problem solving with carefully designed word problems embedded in a computer-supported adventure game called the *Quest of the Silver Owl* (Vauras & Kinnunen, 2003). The computer-supported learning environment was combined with teacher scaffolding because computers cannot replace teachers in supporting low achievers, but can be effective when combined with teacher scaffolding (Kirschner & Van Merriënboer 2013; Kroesbergen & Van Luit, 2003; Lehtinen, 2003; Livingstone, 2012; Xin & Jitendra, 1999). During the intervention, the students were scaffolded in understanding the problem situation to correctly select the mathematical operations, in carrying out the calculations, and in evaluating the solution (cf. Greer et al., 2009; Montague, Warger, & Morgan, 2000; Vauras, Kinnunen, Kajamies, & Iiskala, 2003). The intervention students participated in pairs in 14 intervention game lessons conducted by the researcher as a teacher (two lessons/week). Each lesson lasted approximately 45 minutes. Figure 7 describes the interaction setting during the intervention with a still picture.
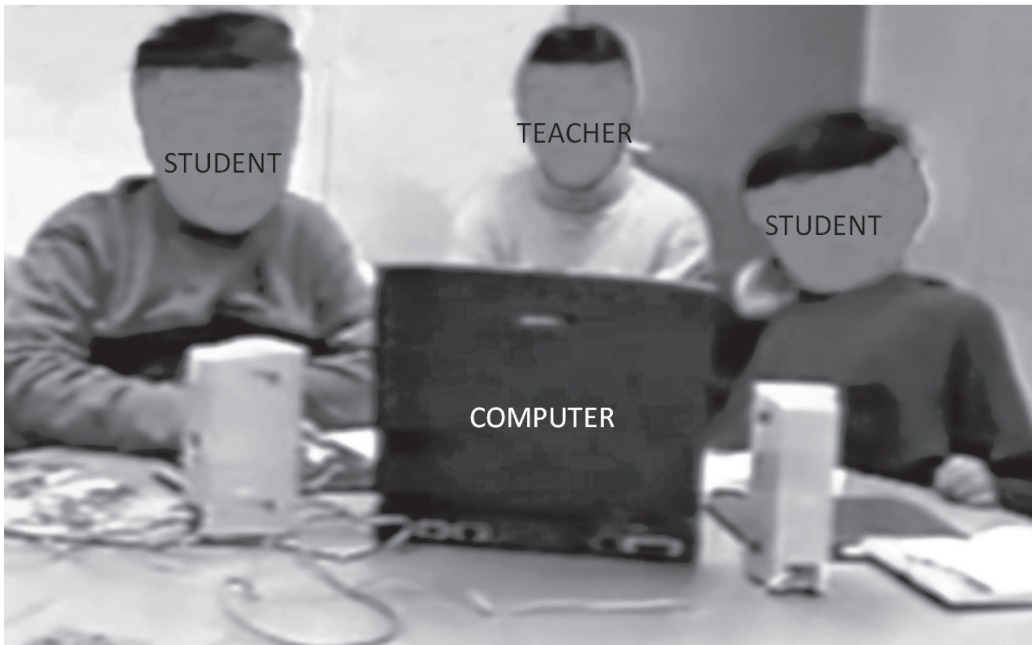
Figure 7. Interaction setting in the word problem solving intervention at grade 4

The adventure game structure, multiple feedback on progress and attractive graphics were used to help the low achievers become deeply engaged in the problem solving. Two built-in game wizards gave game instructions, a picture of the problem, and verbal hints (upon request). The adventurer in turn chose the difficulty of the problem. The more difficult a problem was, the more points the adventurer in turn could obtain by providing the correct answer. The other adventurer checked the answer and was given one point if s/he was able to correctly assess the other student's solution. Figure 8 describes the game environment with a screen shot.
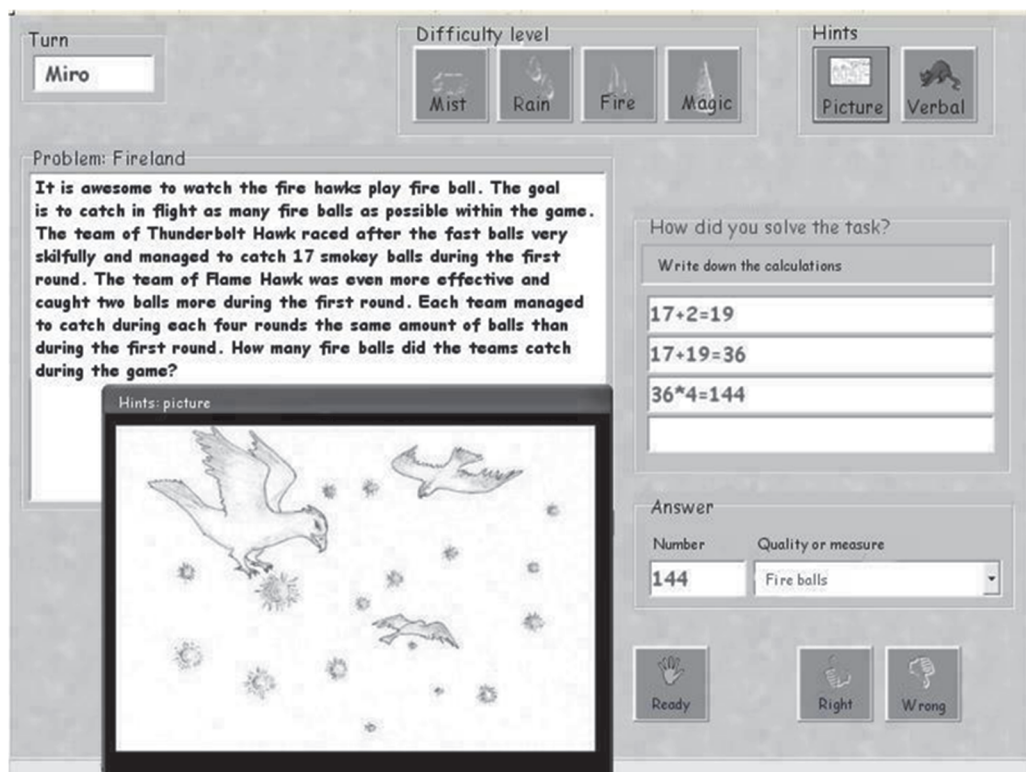
Figure 8. Word problem solving game environment

Transcript 5 gives a shortened example of two low achievers' (Monica and Anna) solving process and a teacher's (Anu) scaffolding during the task presented in Figure 8, because article Kajamies, Vauras, and Kinnunen (2010) did not include any examples of scaffolding interactions.

> Anna chooses a problem from Fireland and reads the task aloud.
> Monica: Let's take a picture.
> Anna opens the picture, looks at it carefully and counts the balls: There are 17 fire balls altogether.
> Anu: Yes. Let's look from the text what amount this 17 is. Who gets 17?
> Monica: The team of Thunderbolt Hawk.
> Anu: Yes. And then what do you have to find out?
> Monica: How many did they catch altogether? It is said in the text that the team of Flame hawk caught two balls more. Then you could add 2 to 17 and get 19. Then you count 19 plus 19, or two times 19.
> Anu: What amount would we get, if we counted two times 19? Whose amount would we get?
> Monica: Altogether.
> Anu: Hmm. Let's take your notebooks and draw there two teams. Let's draw what the situation is like. How many teams?
> Anna: Two.

Anu: Yes.

Monica: How do I draw it?

Anu: You could, for example, draw two birds and write names under them.

The girls draw.

Anu: How much did they catch?

Anna: The team of Thunderbolt hawk got 17 smokey balls. Then, the team of Flame hawk caught two balls more.

Anu: Yes. Good.

Anna: So 17 plus 2 is 19. Flame hawks had 19.

Anu: This is the situation after the first round (shows the picture in Monica's notebook). The other team gets 17, and the other gets 19. Let's write down the first calculation.

Monica: Then it is 17 plus 2. And then $19 + 17 = 36$.

Anu: Yes. And what did we find out?

Monica: Then we got how much they have caught together.

Anu: Yes. Is it the answer?

Monica: Yes it is.

Anna: Is it right?

Monica: Yes.

The program gives the feedback: Wrong.

Anna: Why didn't you tell us that it is wrong?

Anu: I let you think by yourselves, because you need to learn to evaluate yourselves.

Monica: I'm not able to count anymore. The task is impossible.

Anu: Let's read the task once more.

Anna and Monica read the task aloud.

Monica: 19 times 4.

Anu: Why?

Monica: Because it said four rounds. 36 divided with 4—it can't be.

Anu: Let's think for a while. What have you figure out? What is this 36?

Monica: Fire balls altogether.

Anu: In what time?

Monica: In one team or such.

Anu: Isn't it in one round?

Monica: Then this is divided....

Anna: Divided! What are you mucking around? Just a moment ago, you said that multiply. Now you say that divide. I guess next you say that add.

Anu: Now you are just guessing. What have we found? Let's look from your notebooks what we have done. The amount of Thunderbolt hawks was told in the text. How much did the team of Thunderbolt hawks catch in the first round?

Monica: 17.

Anu: Good. How much did the team of Flame hawk catch?

Monica: 19.

Anu: Yes. And then you added them together. What did you find out?

Anna and Monica: 36.

Anu: What is this 36?

Monica: Fire balls altogether.

Anu: In the first round, isn't it?

Monica: Yes.

Anu: Now you have 4 rounds that are like the first. How can you find out how much they got altogether in the four rounds? If they get 36 fire balls in the first round, how can

we find out how much do they get altogether in four rounds? How much did they get in the first round?
Monica: Altogether 36.
Anu: Then they play the second round.
Anna: 36 plus 36.
Anu: Yes, yes!
Anna: It is 72.
Anu: Then it is what they have caught in two rounds.
Monica: I'm not able to solve this same task anymore.
Anu: Let's think still a little while. We are near the solution here.
Monica: Yes, we are.
Anu: You find out how much they caught in two rounds. How many rounds were there?
Anna: Four.
Anu: How could it be solved?
Anna: 72 plus 72.
Anu: Yes. Then we have the amounts in all rounds.
Anna: 144.
Anu: Yes. Very good!
The program gives the feedback: Right.

As Transcript 5 demonstrates, the students had difficulties understanding the problem situation. Teacher scaffolding was needed to help the students engage in and reflect upon the cognitive–metacognitive and motivational–emotional domains involved in skillful problem solving. With support from the teacher and the learning environment and following a 24-minutes solving process, the students finally reached the correct solution.

3.3.2. Scaffolding comprehension skills with dialogic reading

In **Studies II through IV**, we designed dialogic reading interventions in adventure story environments to scaffold reading and listening comprehension skills. To support the teachers in the implementation of optimal scaffolding principles, we provided guidebooks, all materials, and a professional development program. The guidebook included a carefully designed structure and tasks for each session to support progress towards the aims of the intervention. The children were encouraged to participate actively in the discussion of stories and story-related tasks to practice comprehension skills and strategies proven to be effective in earlier studies (Dickinson et al., 2012; Gajria et al., 2007; John, 2009; Lever & Sénéchal, 2011; Mol et al., 2008; Pressley, 2005; Whitehurst & Lonigan, 1998). In Studies II and III, the teachers discussed the youth mystery book *Threat in the Desert Island* (Vauras, 2003) with groups of three students to scaffold the students' reading comprehension skills over the course of 19 lessons (two lessons/week). In Study IV, preschool teachers discussed *Bunny Stories* (Mattinen, Kajamies, Räsänen, Hannula-Sormunen, & Lehtinen, 2014) with groups of two children to scaffold the children's listening comprehension skills over the course of 20 sessions (one session/week). Figures 9 and 10 describe the intervention interaction settings with still pictures.
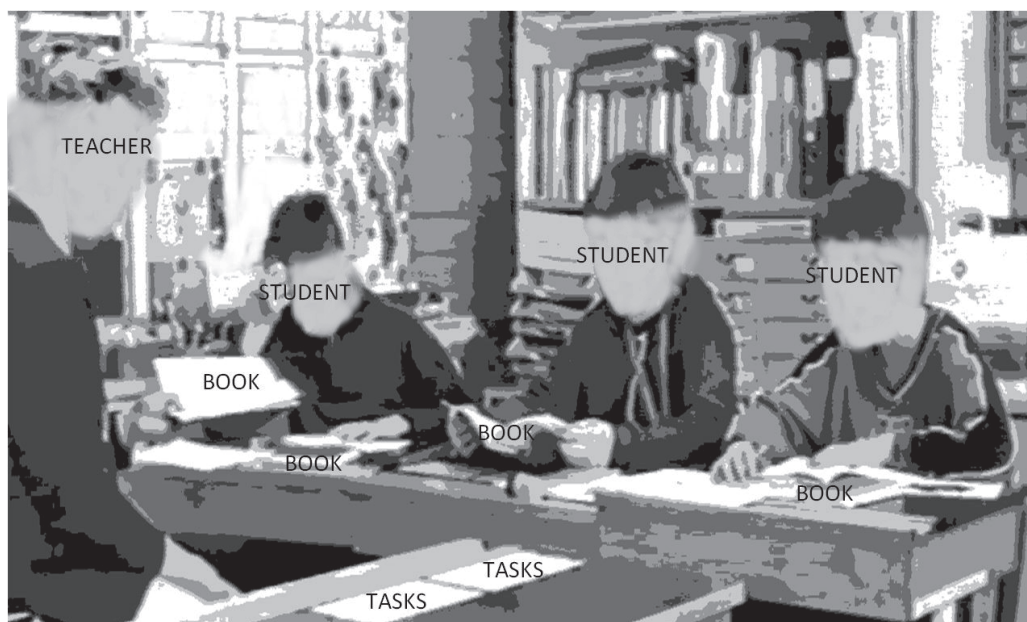
Figure 9. Interaction setting in the reading comprehension intervention at grade 4
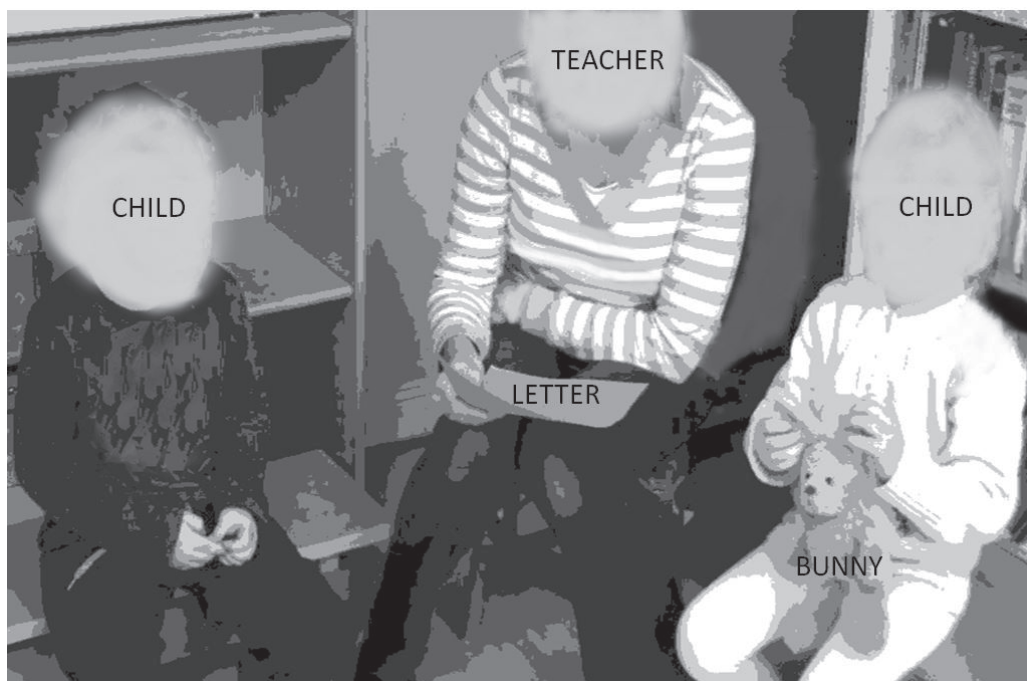
Figure 10. Interaction setting in the listening comprehension intervention at the day care centre

3.4. Analysis

Deepening understanding of intertwined scaffolding dynamics calls for analysis of students' learning, teachers' scaffolding, and scaffolding interactions over time (Cash & Pianta, 2014; Mercer & Dawes, 2014; Pennings & Mainhard, 2016; Praetorius et al., 2014; Rojas-Drummond et al., 2013; Turner & Nolen, 2015). Figure 11 illustrates the focus of the analysis in each study. Studies II and III focused on the scaffolding interactions by scrutinizing intertwined dynamics of students' learning and teachers' scaffolding. Study I focused on students' learning, and Study IV focused on teachers' scaffolding. This means that Study I and Study IV focused on one interaction participant, but left out the other participant, even though naturally all participations happened in the context of teacher–student interactions. All of these aspects of analysis were finally combined to achieve the aims of this dissertation.
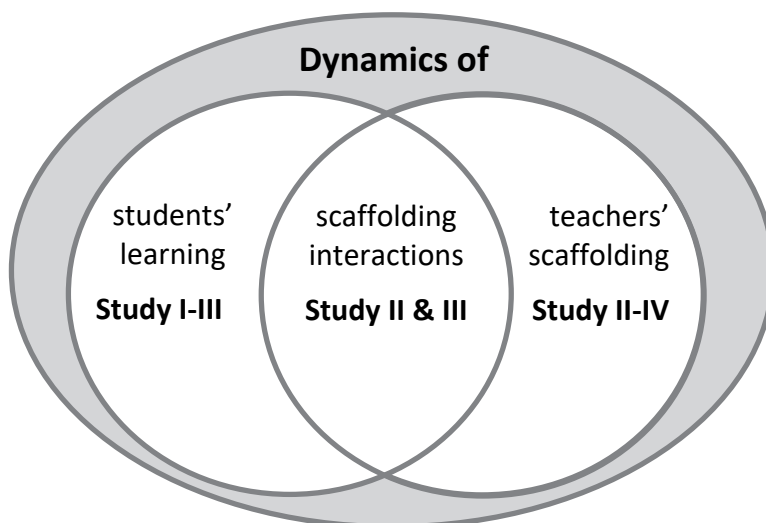
Figure 11. Analysis focus

3.4.1. Analysis of students' learning dynamics

In **Study I,** parallel word problem solving tests were constructed for pre-, post-, and delayed tests and for single-subject measurements (Kajamies et al., 2003). This was crucial for achieving this dissertation's methodological and empirical aims of developing tools to systematically analyze learning dynamics over extended processes and examining the effectiveness of scaffolding on low achievers' learning. Following the intervention, parallel post-tests and follow-up tests were given to all students (n = 429). To increase the reliability of the study, the tests of the students in the experimental groups (n = 24, 5.6%) were scored not only by the researcher, but also separately by a trained researcher who was unaware of the purpose or design of the study. High agreement percentages (97–99%) were obtained. To examine the effectiveness of the

scaffolding, inter-group differences were analyzed using a parametric one-way analysis of variance (ANOVA), an analysis of covariance (ANCOVA), non-parametric Kurskal Wallis tests, and effect size measures (Cohen, 1988; Ives, 2003). Statistically significant differences were further analyzed with post hoc and contrast tests. The effectiveness of the intervention was also evaluated at the individual level.

To scrutinize the intervention students' learning dynamics, the single-subject design required the intervention students to be evaluated before, during, and after the intervention with 19 parallel word problem solving tests. The students' learning dynamics were described by time-series figures with mean lines (see Figure 12). The figures were analyzed to identify changes in levels, trends and variability (cf. Franklin, Allison, & Gorman, 1996). Means, standard deviations, and effect sizes are all given because visual analysis alone does not establish whether an intervention has produced changes beyond those that could be achieved by chance (Franklin, Gorman, Beasley, & Allison, 1996; Kromrey & Foster-Johnson, 1996; Robey et al., 1999; Swansson, 1999).
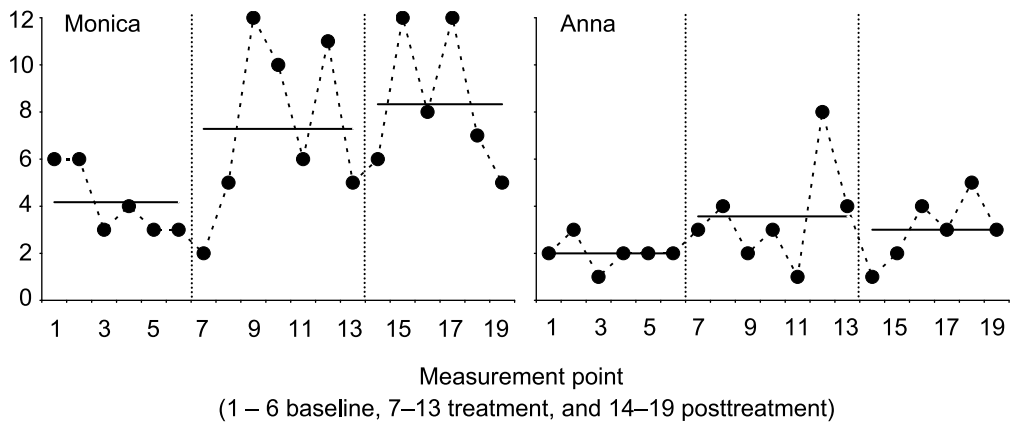
Figure 12. Example of students' learning dynamics (Kajamies et al., 2010)

3.4.2. Analysis of scaffolding interaction dynamics

In **Studies II and III,** systematic video analyses and visual representations with State Space Grids (SSGs) were used to analyze and represent scaffolding interactions in the cognitive–metacognitive domain. The goal was to achieve this dissertation's methodological and empirical aims of developing tools to systematically analyze and represent educationally meaningful interaction patterns over extended processes and examining the usefulness of analytical tools in understanding scaffolding practices. Analyzing scaffolding interactions is challenging, because both students' learning and teacher's scaffolding need to be scrutinized as intertwined and dynamic processes (Gresalfi et al., 2012; Van de Pol et al., 2015; Van Vondel et al., 2016). To facilitate a deep understanding of scaffolding interactions, dynamic system methods (Hollenstein, 2013; Kunnen & Van Geert, 2012; Pennings & Mainhard, 2016) were applied. These

methods capture intertwined processes as they unfold over time and at different levels (Fischer & Järvelä, 2014; Goldman, 2014). Specifically, they focus on the moment-to-moment real-time co-ordinations of opportunities created and taken up by both teachers and students, since systemic studies of the intertwined and dynamic natures of these opportunities are needed to theoretically deepen our understanding of scaffolding and to provide evidence-based ways of increasing optimal scaffolding.

To face the methodological challenge of capturing intertwined and dynamic scaffolding interactions, all verbal and relevant nonverbal participation of the selected teachers and their low achievers were systematically analyzed from videos with the professional computer program *Observer XT*. The strategic level was coded for each contribution according the coding categories developed based on reading comprehension research (Gajria et al., 2007; Kintsch & Kintsch, 2005; Paris et al., 2005; Pressley, 2005; Taylor et al., 2002). The progression from the off- to the meta-strategic level created stronger opportunities to practice reading comprehension (see Figure 13). A contribution was defined as a participant's continuous participation at the same strategic level.

Level	**Off**-strategic	**Pre**-strategic	**Strategic**	**Meta**-strategic
Description	Not connected to strategy learning or reading	Practicing sub-skills necessary, but not alone sufficient for strategy learning	Strategies practiced with explicit links to the aims of the intervention	Applying and transferring at the strategy level
Typical examples	*Off-task activities, arrangements, or classroom management*	*Reading or working with reading-related tasks* *Strategy-practicing, but superficial in relation to the aims of the intervention*	*Activating prior knowledge, selecting main ideas, summarizing or comparing information, or monitoring or regulating comprehension*	*Elaborating on how, why, or when strategies are used in different situations*

Note. The parts of the level names in bold are used in the grid figures.

Figure 13. Levels of strategic participation (Kajamies et al., in review; Vauras, Kinnunen, Kajamies, & Lehtinen, 2013)

To systematically integrate both teacher and student participation, which are typically observed separately in educational settings (Pennings et al., 2014), codes assigned to

each participant were exported as interaction pairs from Observer to *Gridware* (Hollenstein, 2013). Pairs were formed by combining the teacher's contribution with the subsequent student contribution. This was seen as the most useful way to integrate opportunities created and taken up during most typically teacher-initiated interactions, which flowed between the teacher and a student at a time, and then moved between the teacher and another student (see Transcripts 1-4). If more than one student contribution followed the teacher's contribution, the pair was formed by combining the teacher's contribution with the highest subsequent student contribution (see details in Vauras et al., 2013). In this way, an individual student's contribution was not focused separately from the group context, but the focus was on how the students interdependently, as a part of the group, contributed to interaction dynamics (cf. Granott, 1998; Iiskala, 2015; Turner & Nolen, 2015). Pairs were plotted on SSGs to create visual representations of the intertwined and dynamic scaffolding interactions (see Figure 14). The SSGs and related measures were used to illustrate and summarize moment-to-moment scaffolding interaction dynamics, attractors, repellors, and developmental phase transitions. The observed scaffolding interactions were contrasted using the optimal scaffolding model to deepen our understanding of the intertwined and dynamic nature of evolving optimal and non-optimal scaffolding patterns.
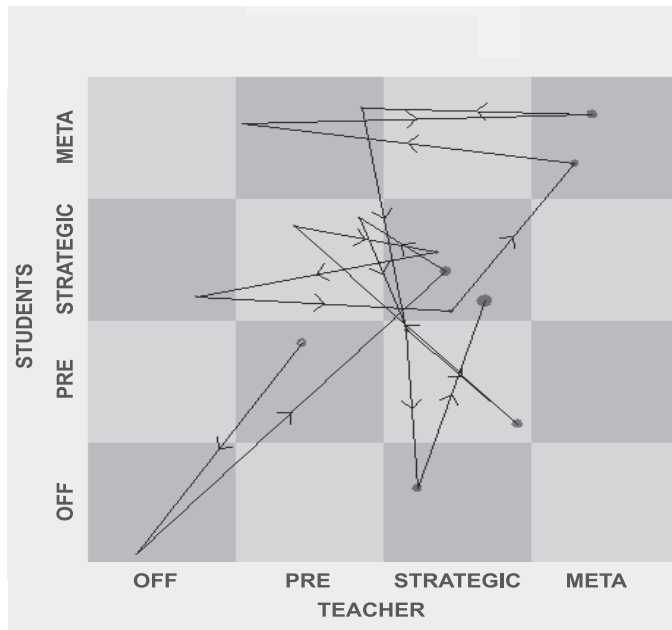
Note. In SSGs, each interaction pair is described as one event node. The size of the node corresponds to the duration of the pair, but the positioning of the node in a cell is randomized. The nodes are combined with transition lines to illustrate the scaffolding dynamics.

Figure 14. Example of scaffolding interactions visualized with SSGs

In **Study II**, to give an idea of the overall participation of the teacher and the individual students, visualizations from Observer XT of all contributions and their durations during the three example lessons were shown. Successful and failed scaffolding interactions were described using SSGs.

In **Study III**, the long-term scaffolding interactions of two groups over the entire 19-lesson intervention were scrutinized, since doing justice to scaffolding dynamics calls for greater insight into the development of interactions over time (Cash & Pianta, 2014; Iiskala, Volet, Lehtinen, & Vauras, 2015; Mercer & Dawes, 2014; Pennings & Mainhard, 2016; Rojas-Drummond et al., 2013). Altogether 21,428 contributions (group A: 6,832, group E: 14,596) were coded, and 7,991 pairs (group A: 2,680; group E: 5,311) were formed. The majority of the lessons were analyzed separately by the researcher and the co-coders. Inter-coder reliability was calculated using Observer by comparing the timing, frequency, and sequence of contributions (Jansen, Wiertz, Meyer, & Noldus, 2003). It ranged from substantial to almost perfect (Cohen 1960; Landis & Koch, 1977). Differences between and within groups with respect to the emergence of scaffolding interactions were analyzed using parametric tests (Student's T-tests), non-parametric tests (Mann-Whitney U-test or Wilcoxon signed ranks z-test), and effect size measures (Cohen, 1988; Fritz, Morris, & Richler, 2012). Regression analyses were used to analyze the linear development of the interactions that occurred during the intervention (Field, 2013) and time-series figures were used to visualize the evolution of the scaffolding interaction dynamics.

3.4.3. Analysis of teachers' scaffolding dynamics

In **Study IV,** to deepen understanding the multi-domain nature of scaffolding in the motivational–emotional domain, the teachers' emotional scaffolding was scrutinized. The analysis of the teachers' emotional scaffolding was founded on self-determination theories (Stroet et al., 2013; Turner et al., 2014; Vansteenkiste & Ryan, 2013). Analysis categories were developed on the basis of the emotional support dimension in the well-known and widely used, multi-dimensional Classroom Assessment Scoring System (CLASS, Pianta, La Paro, & Hamre, 2008). CLASS is based on rating the instructional support, classroom organization, and emotional support after observing these multi-dimensional aspects of classroom interactions during 20 minutes. We used the items of emotional support from CLASS to develop a tool which enables a continuous, systematic, detailed and exact observation of positive, neutral and negative emotional support. This kind of tool was needed to get an insight into teachers' on-going emotional support. Videos of four preschool teachers from the Bunny Stories intervention context were used to adapt and further develop the emotional support categories of CLASS into the dialogic day care reading context.

The categories of emotional support are described in Figure 15. The main categories of emotional support called 'Climate' and 'Regard for children's perspective' are also a

part of CLASS. The main category of emotional support called 'Teacher sensitivity' in CLASS was not dealt with as a category of its own, but it was viewed as belonging to 'Regard for children's perspective' category. Typical examples can be found in the original publication.

Emotional support			
	Positive	*Neutral*	*Negative*
Climate	Positive	Neutral	Negative
Regard for children's perspective	in a supportive or encouraging manner	in a low key or neutral manner	negative, emphasis on teacher's perspective

Figure 15. The categories of emotional support (Kajamies, Mattinen, Kaurila, & Lehtonen, 2016)

All of the selected two preschool teachers' verbal and nonverbal participation activities were systematically analyzed from the videos using the professional computer program *ELAN* (Lausberg & Sloetjes, 2009). Using the developed categories, we observed the positive, neutral, and negative emotional support developmentally across the intervention, the variations in emotional support during single reading sessions, and the typical expressions of emotional support. Codes were assigned according to the strongest emotional support observed. One emotional support category was coded until there was reason to assign another. When two observers had analyzed the videos independently, their analyses were compared. The agreement for positive emotional support was 68%, that for neutral support was 72%, and that for negative support was 73%. General developmental views and different kinds of developmental profiles for preschool teachers' emotional scaffolding were illustrated. Time-series figures were used to visualize scaffolding dynamics and to identify educationally meaningful consistent and inconsistent phases of emotional support.

4. Overview of the empirical studies

This dissertation includes four longitudinal case studies that deepened our understanding of the dynamic, intertwined, and multi-domain nature of low achievers' optimal scaffolding. Study I demonstrated that low achievers' skills progress when they are given optimal, multi-domain scaffolding and highlighted the importance of in-depth analyses of scaffolding interactions. The three subsequent studies developed ways to systematically analyze dynamic and intertwined scaffolding. Studies II and III unpacked the nature of cognitive–metacognitive scaffolding. Study IV began to explore the nature of motivational–emotional scaffolding.

Study I

Kajamies, A., Vauras, M., & Kinnunen, R. (2010). Instructing low achievers in mathematical word problem solving. *Scandinavian Journal of Educational Research, 54(4),* **335–355.**

The aim of this intervention study was to determine the effectiveness of multi-domain scaffolding on low achievers' learning. We designed an intervention to develop the cognitive–metacognitive and motivational–emotional components necessary for mathematical word problem solving. To overcome challenges reported in earlier studies in scaffolding low achievers' complex skills, our intervention combined teacher scaffolding with carefully designed word problems embedded in a computer-supported adventure game. During the instructional discussions, the low achievers were scaffolded to become active, strategic, and motivated problem solvers. Questioning, feedback, and modelling were used to scaffold the low achievers in understanding the problem situation and correctly selecting the mathematical operations, in carrying out the calculations, and in evaluating the solution. As the low achievers showed increasing mastery, the teacher faded out her scaffolding and encouraged them to take on more responsibility. The adventure game structure, the possibility to select each task's difficulty level, the multiple feedback on progress and the attractive graphics all helped the low achievers become deeply engaged in problem solving.

To evaluate the effectiveness of the intervention, we constructed parallel word problem solving tests. Altogether, 429 general education fourth grade 10-year-old students participated in our study. Intervention students (n = 8) and two pairwise-matched controls for each intervention student (n = 16) were selected from low achievers in word problem solving among the total sample (below 32%, n = 138). Word problem solving, arithmetical skills, nonverbal intelligence, and task orientation were used as matching criteria. The intervention students participated in pairs in 14 game lessons,

each 45 minutes long, conducted by the first author. Half of the control students received no special attention during the intervention, while the other half took part in reading comprehension interventions implemented by teachers in the larger Quest for Meaning project, of which this study was a part.

At the group level, some positive and lasting effects for the intervention group's word problem solving were indicated by the statistically significant test results and the moderate effect sizes from the pre-test, the post-test, and the follow-up test comparisons. After the intervention, the intervention group's word problem solving skills no longer differed from those of other students (n = 405) who served as a comparison group to establish the typical skill level of the age group. By contrast, the control groups' skills were still below the typical level. When the individual learning dynamics behind the group levels were scrutinized, large intra- and inter-individual variabilities were identified. A single-subject design demonstrated positive development for three students, large fluctuations for three students, stability for one student, and a negative change for one student. Observations showed not only the power of the innovative learning environment to deepen low achievers' engagement in problem solving, but also the challenges in scaffolding low achievers' complex skills.

Based on our encouraging results, it can be concluded that low achievers' word problem solving skills develop if they are provided intensive and systematic multi-domain teacher scaffolding in a carefully designed computer-supported learning environment. The students' individual learning dynamics demonstrated the low achievers' sensitivity to situational factors and emphasized the need to evaluate the students' skills at different time points when trying to scaffold their learning. The interesting variability in the low achievers' development and the vital role of the instructional discussion between the low achievers and the teacher during the intervention highlighted the importance of conducting in-depth analyses of scaffolding interactions to deepen our understanding of the most optimal ways to scaffold low achievers. These findings formed the basis of Studies II through IV.

Study II

Vauras, M., Kinnunen, R., Kajamies, A., & Lehtinen, E. (2013). Interpersonal regulation in instructional interaction: A dynamic systems analysis of scaffolding. In S. Volet & M. Vauras (Eds.), *Interpersonal regulation of learning and motivation. Methodological advances, pp. 125–146.* **New perspectives on learning and instruction. NY: Routledge.**

The aim of this study was to establish the potential of dynamic interaction analysis to scrutinize scaffolding. We introduced an educational application of the State Space Grid (SSG, Hollenstein, 2013) method for analyzing teachers' scaffolding in relation to

students' learning in real time. We also built a theoretically integrated approach that uses the concepts of interpersonal positioning, creation, and the take-up of opportunities to interpret interactions illustrated with SSGs. Based on our approach, during scaffolding, students are positioned by moment-to-moment opportunities to participate in particular ways. Over time, different kinds of interpersonal positions become typical (attractors) and rare (repellors) and establish diverse learning trajectories. If student positions are limited to completing tasks with low cognitive demand, they are afforded trajectories that involve acquiring and consolidating basic skills, but that do not progress toward high-level understanding. To successfully support learning in the cognitive–metacognitive domain, scaffolding should include both dynamic matches between opportunities created by the teacher and taken up by the students and opportunities created by the teacher at a higher level than the students' subsequent participation.

Scaffolding was analyzed in Studies II and III in the context of a reading comprehension intervention. We designed the multi-domain intervention to optimally scaffold low achievers reading comprehension strategies via instructional discussions about a youth mystery book and book-related tasks. The experienced teachers (n = 11) who implemented the interventions were genuinely interested in expanding their expertise in scaffolding reading comprehension. To support the teachers, we provided guidebooks, all materials, and a professional development program. The teachers carried out the interventions in groups of three low achievers over the course of 19 lessons. All lessons were videotaped. Low achievers (n = 57) were selected for the intervention from the total sample of 438 general education fourth grade students on the basis of their reading comprehension difficulties and motivational vulnerability evaluated with the tests and scales developed in this study.

Methodological illustrations were produced for this study by analyzing opportunities created and taken up between a special needs teacher and three low achievers during three lessons (group A, lessons from the beginning, middle, and end of the intervention). The strategic level of each contribution in the selected group was coded according the categories we developed based on the reading comprehension research. At the low level, the codes included off-strategic and pre-strategic, and at the high level, they included strategic and meta-strategic. While progressing from the off- to the meta-strategic level, stronger opportunities to practice reading comprehension according the aims of the intervention were created. A contribution was defined as a participant's continuous participation at the same strategic level. SSGs were used to visualize interactions between the teacher's and the low achievers' contributions and to describe attractors, repellors, and developmental phase transitions.

The results showed that participation in all lessons was strongly teacher-dominated. The low achievers participated almost equally, but much less than the teacher. Low-

matched levels formed strong attractors and revealed that many opportunities were created and taken up for practicing and consolidating decoding skills. Interactions at high levels, particularly at the meta-strategic level, served as repellors during all lessons. Missed opportunities were observed when the teacher created strategic opportunities but struggled to pull the low achievers to the higher level and when the teacher failed to take up strategic opportunities created by the low achievers. These missed opportunities showed that the teacher had difficulties calibrating her level of scaffolding to pull the low achievers toward new levels of independent activity through moderate growth-promoting discrepancies.

With these methodological illustrations, we established the power of SSGs in representing and analyzing the turn-by-turn instructional match and mismatch in the cognitive–metacognitive domain. Through dynamic SSGs, it was possible to identify interesting interaction patterns by taking into account, reciprocally, both the students' learning and the teacher's scaffolding. Studying scaffolding interactions has great potential for understanding teachers' expertise and the dynamics behind resistance and resilience to learning. This potential can be explored to help teachers sensitively monitor and flexibly regulate their scaffolding (e.g. in teacher education and in-service training). The methodological and theoretical progress made in Study II formed the basis for scrutinizing scaffolding interactions more systematically during long-term processes in more cases in Study III.

Study III

Kajamies, A., Vauras, M., Kinnunen, R., Lehtinen, E., & Volet, S. (in review). Intertwined and dynamic scaffolding of low achievers' reading comprehension strategies.

The aim of this study was to deepen our understanding of the intertwined and dynamic nature of evolving optimal and non-optimal scaffolding interactions in the cognitive–metacognitive domain. We detailed the optimal scaffolding model by focusing on matches and opportunities as dynamically intertwined scaffolding zones. We further developed the applications of the SSG method for studying the development of micro-level interactions into long-term interaction patterns. Our goal was to demonstrate how fine-grained analyses of interaction dynamics unveil both teachers' flexibility in adapting to low achievers' needs and low achievers' readiness for challenges during long-term scaffolding.

We used systematic video analyses, visual representations with SSGs, and statistical analyses to capture and summarize opportunities created and taken up in two small groups (groups A and E comprising two teachers [called here Anna and Eeva] and six low achievers). Both groups participated in the reading comprehension intervention

developed in Study II and interactions were analyzed in the same way as in Study II. To reveal the intra- and inter-system stability and variability during the extended scaffolding processes, all intervention lessons were analyzed (19 lessons/group, altogether 21,428 contributions, 7,991 interaction pairs). Inter-coder reliability was evaluated and ranged from substantial to almost perfect.

The results demonstrated that low-level matches were too typical and high-level matches too rare during long-term scaffolding. Pre-strategic matches were more typical than any other type of interaction. Optimal scaffolding of reading comprehension was threatened, since there were too few strategic matches in which both the teacher and the low achievers participated according the goals of the reading comprehension strategy intervention and too many off-strategic matches in which both the teacher and the low achievers participated in ways not connected to strategy learning or reading. The low achievers were more likely to take up the teacher's low-level participation at the matched level than they were to take up her high-level participation. At a meta-strategic level, both matches and opportunities were rare. Crucial group differences showed that Eeva took more responsibility for scaffolding the low achievers' participation to higher levels than Anna and also achieved more strategic matches. Eeva also took more responsibility for interacting according to the aims of the intervention than her low achievers did, but Anna took as much responsibility as her low achievers.

Based on the optimal scaffolding model, we expected an increase in high-level matches and a decrease in low-level matches during the intervention. However, there were no statistically significant linear changes in any of the matched interactions. The most promising but, unfortunately, frequently missed potential for development emerged when either the teacher or the low achievers created strategic opportunities by participating at a higher level than the other participant. We also expected an increase in opportunities created by the teacher during the intervention. However, Anna did not increase and Eeva even decreased high-level opportunities. Interestingly, there was a statistically significant linear increase in the high-level strategic opportunities created by the low achievers in both groups, clearly showing the low achievers' learning during the intervention. Unfortunately, the low achievers' increasing readiness for strategic participation was not flexibly taken up by the teachers. Furthermore, the teachers' success in achieving strategic matches did not increase, but instead varied extensively, revealing challenges related to finding effective and reliable ways to support the low achievers' take-up of the most important opportunities. In scrutinizing the evolution of the interactions more closely, educationally interesting fluctuations and non-linear developments were also observed.

This study answered the calls for the development of conceptualizations, analyses, and practices of scaffolding by deepening our understanding of the intertwined and

dynamic nature of cognitive–metacognitive scaffolding and providing methods to scrutinize evolving optimal and non-optimal scaffolding patterns across extended processes. The results emphasize the urgent need to continue developing collaborations between researchers and teachers to increase optimal scaffolding. More research is needed on how matches and opportunities at different levels should be intertwined to secure optimal scaffolding during extended processes and how this optimality depends on dynamic systemic elements, including, particularly, the learning goals, the environment, and the interaction participants. Future research was challenged to understand the multi-domain scaffolding in both the cognitive–metacognitive and the motivational–emotional domains to deepen our understanding of the systemic formation and maintenance of learning dynamics. In Study IV, the next step toward this grand goal was taken by scrutinizing teachers' emotional scaffolding.

Study IV

Kajamies, A., Mattinen, A., Kaurila, M.-L., & Lehtonen, E. (2016). Emotional support constructing high quality scaffolding in day care. *Journal of Early Childhood Education Research, 5(1),* **162–188.**

The aim of this study was to gain insight into the nature and evolution of scaffolding in the motivational–emotional domain. We developed a systematical observation method to deepen our understanding of teachers' emotional scaffolding and its variation during interaction processes. We aimed to provide evidence-based ways to improve the quality of scaffolding, since positive emotional support provides a good starting point for the scaffolding of motivation and learning and may function as a protecting factor, especially for at-risk children. We built on theoretical approaches integrating theories of attachment and self-determination by emphasizing the importance of adults' sensitivity and responsiveness in emotionally supporting children's basic psychological needs of autonomy, belongingness, and competence.

Emotional scaffolding was analyzed in the early education dialogic reading intervention context, since reading sessions create excellent opportunities for positive emotional support, which is strongly linked to high-quality scaffolding during early childhood. We designed the multi-domain intervention to optimally scaffold low achievers' listening comprehension with instructional discussions around Bunny stories. The preschool teachers (n = 21) carried out the interventions in groups of two 4-year-old children over the course of 20 lessons and were provided guidebooks, all materials, and a professional development program. All sessions were videotaped. Videos of four preschool teachers were used to develop the emotional support categories based on the multidimensional Classroom Assessment Scoring System (CLASS, Pianta et al., 2008). With the developed categories, we observed the positive, neutral, and negative emotional support of two preschool teachers, called here Petra

and Leena, developmentally across the intervention; the variations in emotional support during single reading sessions; and the typical expressions of emotional support. For both cases, two observers analyzed three video sessions drawn from the beginning, middle, and end of the intervention. Both preschool teachers had worked in day care for many years and were enthusiastic about developing their scaffolding through reflection.

The results showed that the preschool teachers provided mainly positive or neutral emotional support and seldom offered negative emotional support. Leena provided more positive emotional support and had more and longer consistent, learning-supportive phases in her emotional support than Petra, whose emotional support was mainly neutral. However, Leena's emotional support showed more inter-session variation than Petra's. During the middle session, Leena's emotional support was mainly neutral, while during the beginning and end sessions, it was mainly positive. Petra, by contrast, offered scant positive or negative emotional support in all sessions, though, by the end, her neutral emotional support increased and her positive support decreased. Inconsistent and consistent variations of emotional support, both of which could be harmful to learning, were also observed. Consistent harmful-to-learning phases were observed in Petra's mainly neutral emotional support during each session. Particularly during the end session, Petra faced challenges consistently providing positive emotional support; this session contained no phases that supported learning and two quite long phases that were harmful to learning. Positive emotional support typically manifested as engaged reading, positive feedback, and encouraging facial expressions. Negative emotional support was typically shown by insensitivity and inflexibility to children's perspectives.

With the help of the systematic observation method, it was possible to scrutinize differences between the cases and the stability and variability of the teachers' emotional support. The results emphasize the need to pay greater attention to emotional support to construct high-quality scaffolding with consistent positive emotional support. The emotional support classification developed offers an in-depth method for recognizing the strengths and weaknesses of emotional support. Applying this method to other kinds of interaction contexts, skill levels, and age groups would increase our understanding of emotional support in different contexts. In the future, emotional interaction could also be investigated from videos from the perspective of the children to deepen our understanding of the complex and systemic nature of emotional interactions by showing how children's participation is intertwined with emotional support.

5. Main findings and discussion

The main aim of this dissertation was to scrutinize the optimal scaffolding of low achievers' learning of complex comprehension and problem solving skills. To face the challenges of scaffolding low achievers' learning, this dissertation aimed to theoretically and empirically deepen our understanding of scaffolding and learning as intertwined, dynamic, and multi-domain processes. The journey towards this aim grew from the scaffolding research tradition, which has typically conceptualized scaffolding as teachers' support that is carefully calibrated to students' learning (Muhonen et al., 2016; Steenbeek et al., Van de Pol et al., 2014; Wood et al., 1976), but which has empirically concentrated on teachers' short-term support without scrutinizing the multi-domain calibration of support for students' learning during long-term processes (Van de Pol et al., 2010). In this dissertation, the focus of scaffolding research was widened from the teacher to the dynamic long-term interactions between teacher and students. To empirically capture these interactions, the methodological aim was to develop tools to systematically analyze the intertwined and multi-domain scaffolding and learning dynamics. Methodological development was inspired by a dynamic systems approach to the development, stability, and variability of interaction processes (Hollenstein 2013; Kunnen & Van Geert 2012; Pennings & Mainhard, 2016). The practical aim in this dissertation was to explore and promote teachers' professional development in optimal scaffolding by identifying and developing scaffolding practices. To achieve these general aims, four intervention studies for low achievers were implemented in a computer-supported mathematical word problem solving context and in a dialogic adventure story reading context. A mixed methods approach with carefully designed tests, quasi-experimental and single-subject designs, and longitudinal in-depth case studies with systematic interaction video observations were utilized in the collection and analysis of the scaffolding and learning dynamics that occurred during these interventions.

The main findings of this dissertation demonstrate that to progress towards optimal scaffolding of low achievers' learning, scaffolding must be scrutinized not only theoretically, but also empirically by combining intertwined, dynamic, and multi-domain perspectives. To face the challenges of optimal scaffolding of low achievers' learning, this dissertation introduces dynamic methods to study scaffolding empirically from a wider perspective than the short-term support provided by the teacher. It shifts the focus from the teacher to the dynamic multi-domain interactions between teacher and students by systematically taking into account both the teachers' scaffolding and the students' learning. Study I took the first steps by determining the effectiveness of multi-domain scaffolding in supporting low achievers' learning dynamics and highlighting the importance of in-depth analyses of scaffolding interactions. Study II and III took the next steps by combining all perspectives to unpack the nature of

cognitive–metacognitive scaffolding interactions using new methodological solutions to analyze evolving scaffolding patterns. Study IV continued by exploring the dynamics of motivational–emotional scaffolding. In the following chapters, the main findings of each study are summarized and discussed.

5.1. Effectiveness of multi-domain scaffolding in supporting learning

Based on the encouraging findings of Study I, it can be concluded that **multi-domain teacher scaffolding is effective in supporting low achievers' learning in a carefully designed computer-supported learning environment.** The evidence for this conclusion comes from the quasi-experimental design, whose statistically significant test results and moderate effect sizes from the pre-test, post-test, and follow-up test comparisons revealed some positive and lasting effects for the intervention group's mathematical word problem solving skills. Following the intervention, the intervention group's word problem solving skills no longer differed from those of the other students who served as a comparison group to establish the typical skill level of the age group. By contrast, the control groups' skills were still below the typical level. This finding, which shows that low-achieving intervention students were able to achieve the typical skill level, is an important contribution to the still scarce evidence of the effectiveness of scaffolding (Swansson, 1999; Van de Pol et al., 2010). Furthermore, Study I, unlike many other intervention studies (see the meta-analyses by Kroesbergen & Van Luit, 2003; Xin & Jitendra, 1999), included a follow-up, which showed that the effects of the scaffolding were maintained even after the intervention itself was over helping students respond to increasing learning demands at school (Gresalfi et al., 2012; Haber et al., 2016; Meichenbaum & Biemiller, 1998). These positive group-level findings are in line with earlier studies, which have highlighted scaffolding in both the cognitive–metacognitive and the motivational–emotional domains as a solution to the challenges of scaffolding of low achievers' mathematical word problem solving skills (De Corte et al., 2011; Greer et al., 2009; Pongsakdi et al., 2016; Verschaffel et al., 2000).

The intensive longitudinal and time series data on students' learning dynamics collected in Study I deepens our understanding of the effectiveness of scaffolding. When the individual learning dynamics behind the group levels were scrutinized, interesting intra- and inter-individual variabilities were identified. The individual learning dynamics suggest that **the effectiveness of multi-domain teacher scaffolding in supporting low achievers' learning in a carefully designed learning environment varies within and between students**. Evidence for this conclusion comes especially from the time series data in the single-subject design, which demonstrated positive development for three intervention students, large fluctuations for three intervention students, stability for one intervention student, and a negative change for one intervention student. Large variabilities in learning processes and outcomes underlined a need to evaluate students' skills at different time points when

determining the effectiveness of scaffolding on their learning, a point that has also been highlighted in earlier studies (Gates & Liu, 2016; Kromrey & Foster-Johnson, 1996; Robey et al., 1999; Swansson, 1999). The observed variability also emphasized the importance of developing teachers' skills to diagnose and observe low achievers' learning dynamics, which is one of the challenges of optimal scaffolding (Begeny et al., 2011; Chi et al., 2004; Herppich et al., 2013; Hurwitz et al., 2007; Südkamp et al., 2012; Van de Pol et al., 2011). A detailed understanding of students' learning dynamics is crucial for making evidence-based decisions to increase the optimality of scaffolding during long-term interventions.

Because of the multi-domain nature of the skills needed in mathematical word problem solving (Verschaffel et al., 2000) and the challenges of scaffolding the skills of the low achievers (Broza & Ben-David Kolikant, 2015; Vauras et al., 2009), it is not reasonable to individually evaluate the importance of the different components of the intervention in the production of the effects. This kind of perspective on the components of complex multi-domain interventions has also been taken in some earlier studies, which have claimed that all components together were responsible for the effectiveness of the intervention (Brown, Pressley, Van Meter, & Schuder, 1996). Our observations showed both the power of the innovative learning environment in deepening low achievers' engagement in problem solving and the vital role of the instructional discussion between the low achievers and the teacher during the intervention. The observations also provided evidence that, when combined with teacher scaffolding, computer-supported learning environments can be effective, a finding that has also been highlighted in earlier studies (Kirschner & Van Merriënboer 2013; Kroesbergen & Van Luit, 2003; Lehtinen, 2003; Livingstone, 2012; Xin & Jitendra, 1999). Furthermore, the observations, together with variabilities in learning dynamics within and between students, emphasized that **careful, on-going calibration of the multi-domain support provided by the teacher and the learning environment is vital in optimally scaffolding each student's progress** towards learning goals during long-term interventions. Finally, the observations highlighted the importance of conducting in-depth analyses of on-going scaffolding interactions to deepen our understanding of the most optimal ways to dynamically calibrate the scaffolding of low achievers' learning processes. In addition to revealing the dynamic nature of students' learning, these findings highlight the importance of scrutinizing the intertwined and dynamic nature of scaffolding interactions between teacher and students.

5.2. Intertwined and dynamic nature of evolving scaffolding patterns

In Studies II and III, dynamic systems methods, representing educational applications of the State Space Grid (SSG, Hollenstein, 2013), were introduced and developed further to scrutinize micro-level scaffolding interactions and their development into

long-term scaffolding patterns. Furthermore, a theoretically integrated optimal scaffolding model was constructed to interpret the intertwined and dynamic nature of scaffolding interactions illustrated with SSGs. Methodological illustrations with SSGs were produced by systematically analyzing from videos opportunities created and taken up by the teachers and the low achievers in the two groups, according to the categories developed based on earlier reading comprehension research (Gajria et al., 2007; Kintsch & Kintsch, 2005; Paris et al., 2005; Pressley, 2005; Taylor et al., 2002).

5.2.1. Focusing on the intertwined nature of scaffolding patterns

Studies II and III demonstrated that low-level matches were too typical and high-level matches too rare during long-term scaffolding. These findings mirror those of earlier teacher–student interaction research (Hamre et al., 2013; Hedin & Gaffney, 2013; Howe & Abedin, 2013; Mehan, 1998; Muhonen et al., 2016; Pianta & Hamre, 2009). The findings of this dissertation specified the earlier results of teachers' challenges in scaffolding low achievers' complex skills (Baxter et al., 2002; Mercer & Dawes, 2014; Palincsar, 1986; Vauras et al., 2008) by demonstrating that low achievers were more likely to take up a teacher's low-level participation at a matched level than they were to take up high-level participation. This finding **highlighted scaffolding challenges in low achievers' take-up of high-level opportunities and stressed a need to strengthen teachers' skills in supporting students' take-up of these opportunities**, which are pivotal for their learning of complex cognitive–metacognitive skills.

This dissertation deepens our understanding of the calibration of scaffolding during a reading comprehension intervention by showing that pre-strategic matches are more typical than any other interaction. A dynamic systems approach would call these recurrent patterns attractors (Hollenstein, 2013). Pre-strategic matched attractors demonstrate that many opportunities for practicing and consolidating decoding skills are created and taken up. Earlier studies have shown that it is essential, but not sufficient to optimally scaffold low achievers in decoding (Crosnoe et al., 2010; Gough & Tunmer, 1986; Kim, 2015; Paris et al., 2005; Taylor et al., 2002; Tiffin-Richards & Schroeder, 2015) because the influence of decoding on reading comprehension decreases after prerequisite skills have become automatic (García & Cain, 2014; Language and Reading Research Consortium, 2015). In the context of a transparent orthography, such as the Finnish language, the direct effect of decoding on reading comprehension wanes after the early school years (Torppa et al., 2016). In our study, the background test information demonstrated that all students from group E and one student from group A had difficulties in decoding, indicating that the low achievers (especially in group E) also needed to practice their decoding skills. However, only few such moments were observed from the videos, in which low achievers struggled with producing fluent and accurate decodings of the texts they were reading during the intervention. From the findings of this dissertation and earlier research, therefore, it can be concluded that **spending nearly half of the**

intervention time on pre-strategic matches did not produce an optimal scaffolding of reading comprehension.

Optimal scaffolding of reading comprehension was also threatened by a lack of strategic matches, in which both the teacher and the low achievers participated according to the crucial goals of the reading comprehension strategy intervention, and an overabundance of off-strategic matches, in which both the teacher and the low achievers participated in ways not connected to strategy learning or reading. This finding deepens our understanding of scaffolding by revealing **challenges in finding an optimal balance between important strategic matches and unimportant off-strategic matches**. The background test information demonstrated that all intervention students had difficulties with reading comprehension. Observations from videos and earlier studies have shown that low achievers typically do not use reading comprehension strategies or monitor their understanding (Gajria et al., 2007; Kinnunen & Vauras, 2010), thus highlighting the need for optimal scaffolding of reading comprehension strategy learning (Guthrie & Klauda, 2014; Palincsar, 1986; Pressley, 2005; Solis et al., 2012; Suggate, 2016; Weed, Keogh, Borkowski, Whitman, & Noria, 2011). Earlier studies have also provided evidence that, without optimal scaffolding of reading comprehension, there is a risk of long-term relative regress of low achievers' comprehension skills (Lepola et al., 2004; Sideridis, 2011; Vauras et al., 1994). The findings of this dissertation also highlight the importance of the teacher avoiding off-strategic participation. The observations demonstrated off-strategic manners and patterns that repeatedly wasted opportunities for student learning. Transcript 2 in the Introduction gave an example of one of such off-strategic interactions during which the group spent a lot of time on a drawing activity that was not related to the goals of the intervention.

At a meta-strategic level, both matches and opportunities were very rare, highlighting ample challenges to include applications or transfers at the strategic level into interactions. The dynamic systems approach would call these patterns repellors (Hollenstein, 2013). Transcripts 3 and 4 empirically illustrated this kind of rare meta-level interaction, in which the teachers tried to scaffold low achievers in the flexible application of strategies practiced during the intervention in other reading comprehension contexts and in understanding the benefits of these kinds of applications. Since both long-term maintenance and the transfer of new skills are severe problems in education, the meta-strategic level should be emphasized in scaffolding interactions. Earlier studies have shown that it is critical to find effective ways to support students' metacognition, motivation, and emotions while scaffolding their learning of cognitive comprehension strategies (Guthrie & Klauda, 2014; Lehtinen et al., 1995; Ng et al., 2013; Pressley, 2005). Transcripts 3 and 4 gave examples of these kinds of multi-domain scaffolding interactions, which are vital in addressing the long-term stabilized motivational–emotional vulnerabilities and self-

regulation difficulties typical of low achievers facing complex tasks reported by earlier studies (Annevirta & Vauras, 2006; Lepola et al., 2016; Meichenbaum & Biemiller, 1998; Schweinle et al., 2008; Vauras et al., 2009).

By systematically considering both the teacher's and the students' contributions, which has not been typical in scaffolding research (Pennings & Mainhard, 2016; Van de Pol et al., 2010), the findings of this dissertation highlight that both teachers and students create vital opportunities. Most typically, both create important strategic opportunities emphasizing the most promising but, unfortunately, frequently missed potential embedded in strategic opportunities for students' strategy learning. The findings of this dissertation further reveal how missed opportunities emerge when a teacher creates high-level opportunities but struggles to persistently pull low achievers to this level or when a teacher fails to take up high-level opportunities created by low achievers. The challenges in teachers' take-up, in particular, have not been sufficiently emphasized in earlier scaffolding research. The findings of this dissertation stress that **teachers should sensitively listen to and flexibly follow up on opportunities created by students by joining them to interactions directed toward learning goals** (cf. Hamre & Pianta, 2007; Muhonen et al., 2016; Salonen et al., 2007).

Crucial group differences were found between the groups. Eeva took more responsibility for scaffolding her low achievers' participation to higher levels than Anna and also achieved more strategic matches. This emphasizes **the essence of opportunities created by the teacher from the perspective of high-level matches achieved**, which has been highlighted in earlier studies (Gresalfi et al., 2012; Van Vondel et al., 2016; Salonen et al., 2005). Eeva also took more responsibility for interacting according to the aims of the intervention than her low achievers did, but Anna took as much responsibility as her low achievers. These findings further indicate that Eeva scaffolded more optimally than Anna, since teachers' responsibility of students' learning has been emphasized in earlier studies (Bransford et al., 2005; Lin et al., 2015; Maloch & Beutel, 2010; Wells & Mejía Arauz, 2006). The interactions in Anna's group (group A) were also less optimal than those in Eeva's group (group E) because group A had more off-strategic matches. No differences were found in the pre-strategic interactions, even though the background test information demonstrated that all students from group E and only one student from group A needed to practice decoding skills. This demonstrates that pre-strategic interactions mismatched even more with the needs of the students in group A than with the needs of the students in group E. These findings regarding the differences between the groups highlight the power of our analysis to identify vital differences between scaffolding interactions. Furthermore, the findings of this dissertation demonstrate how teachers using identical materials develop different scaffolding practices and the relevance of these differences for students' learning.

5.2.2. Focusing on the dynamic nature of scaffolding patterns

To address the lack of earlier rigorous longitudinal studies on dynamic scaffolding interactions, Study III makes a pivotal contribution with respect to increasing our understanding of scaffolding calibration dynamics. The findings based on the regression analyses showed that the scaffolding interaction was not gradually moving toward high levels, as was expected during the long-term intervention according to the optimal scaffolding model. Specifically, an increase in high-level matches and a decrease in low-level matches were expected during the intervention. However, there were **no linear changes in any of the matched interactions**. An increase was also expected in opportunities created by the teacher during the intervention. However, **Anna did not increase and Eeva even decreased her creation of high-level strategic and meta-strategic opportunities**. By contrast, in both groups, there was **a linear increase in the high-level strategic opportunities created by the low achievers**, making clear the low achievers' learning during the intervention. Unfortunately, the low achievers' increasing readiness for strategic participation was not flexibly taken up by the teachers, who failed to increase both high-level opportunities and high-level matches. Furthermore, while both teachers exhibited linear decreases in their success in achieving pre-strategic matches, **their success in achieving strategic matches did not increase, but varied extensively,** revealing challenges related to finding effective and reliable ways to support low achievers' take-up of the most important strategic opportunities. The only optimal development of matched scaffolding dynamics was observed in the linear **increase in Eeva's success in achieving meta-strategic matches**. This suggests that the students' difficulties taking up Eeva's rare and decreasing meta-strategic opportunities decreased during the intervention. The only optimal development of opportunities created by the teacher was observed when **Anna increased pre-strategic opportunities**, demonstrating that she took responsibility for shifting the overly typical off-strategic interactions towards pre-strategic interactions.

Earlier empirical studies have also reported evidence for this kind of non-optimal stability or development of scaffolding dynamics (Kupers et al., 2015; Steenbeek et al., 2012; Turner et al., 2014). This dissertation's findings concerning long-term scaffolding dynamics deepen the findings from earlier research showing that teachers struggle in their roles as sensitive and flexible facilitators (Nathan & Kim, 2009; Salonen et al., 2005). This was evident when the teachers faced severe challenges in systematically raising the level of scaffolding to pull the low achievers toward new strategic levels, despite low achievers' observed readiness. In addition to the challenges in engaging students' active participation in co-constructing understanding highlighted in earlier research (Fredricks, 2014; Fulmer & Turner, 2014; Gresalfi et al., 2012; Reeve & Tseng, 2011; Van Vondel et al., 2016), the findings of this dissertation also reveal how **low achievers create high-level strategic opportunities that the teacher should sensitively notice and flexibly take up** to carefully calibrate long-

term scaffolding to the students' learning dynamics. The systematic video analysis during the extended scaffolding processes in Study III pinpointed the intra-system and inter-system stability and variability considered crucial in understanding interaction processes, which has also been highlighted in earlier research (Flynn & Siegler, 2007; Kunnen & Van Geert, 2012). The long-term analysis unveiled detailed evidence of the intertwined developmental dynamics of both teachers' scaffolding and students' learning at different levels, which are highly relevant for students' learning of complex cognitive–metacognitive skills.

This dissertation's findings concerning long-term scaffolding dynamics deepen our understanding of the key components of scaffolding by emphasizing that **both the fading and the strengthening of scaffolding should be included as key components of scaffolding during long-term processes**. Specifically, teachers are expected to fade scaffolding at the low pre-strategic level and strengthen opportunities at the high strategic and meta-strategic levels. Such an approach would have been highly beneficial in Study III, in which pre-strategic matches were the most typical interactions through the intervention and too little time was spent on strategic matches. Unfortunately, Eeva decreased the creation of strategic opportunities in a way that cannot be considered contingent fading because important strategic matches were not repeatedly achieved. Interestingly, the students faded and strengthened their participation more contingently than the teachers when they decreased their pre-strategic participation and increased their strategic participation following their teachers' pre-strategic participation. Both groups faced challenges finding an optimal balance between important strategic and unimportant off-strategic matches, emphasizing the need to strengthen scaffolding from the off-level towards higher levels. Anna strengthened scaffolding when her pre-strategic opportunities increased linearly. However, unfortunately, this was not sufficient to decrease the too-typical off-strategic matches and increase the pre-strategic matches in her group. Eeva also decreased the creation of meta-strategic opportunities, though she rarely achieved meta-strategic matches. This reveals that she was giving up on—rather contingently fading—scaffolding at the meta-strategic level. These findings emphasize that fading and strengthening need to be scrutinized from both the teacher's and the students' perspective to deepen our understanding of how these key components of scaffolding are dynamically intertwined and construct optimal and non-optimal scaffolding patterns.

5.2.3. Summary of the main findings

The main findings of the intertwined and dynamic nature of scaffolding patterns are summarized in Figure 16.

Note. A = group A, E = group E
Findings from both groups are in boldface. Findings describing the evolution of interactions during the intervention are in italics.

Figure 16. Summary of main findings of the intertwined and dynamic nature of scaffolding patterns (Kajamies et al., in review)

Lack of time is one of the most commonly cited reasons for why optimal scaffolding is challenging to implement. Based on the findings of this dissertation, there is a need to carefully consider **how to optimally spend the very unique time that can be afforded for scaffolding low achievers** (e.g. in small group intervention contexts). If this precious time is spent mostly on scaffolding low-level skills, the optimal development of high-level skills cannot be expected. A more optimal balance between scaffolding low-level and high-level skills than those achieved in Studies II and III needs to be realized. Defining absolute time-based percentages for different levels is not reasonable (cf. Rodgers et al., 2016; Van de Pol & Elbers 2013). However, to be optimal for the learning of complex skills, scaffolding interactions should focus or at least gradually move to a focus on high strategic and meta-strategic levels during long-term processes. Time wasted at off-strategic level should be minimized and time spent for the necessary, insufficient practicing of necessary subskills at pre-strategic level should be carefully regulated and decrease as students show increasing readiness for

high-level challenges. Otherwise, typically limited resources should be more optimally used to support low achievers' learning of complex skills. Thus, as has been highlighted in earlier studies, the main responsibility for time management lies on teachers' shoulders (Bransford et al., 2005; Lin et al., 2015; Maloch & Beutel, 2010; Turner et al., 2014; Wells & Mejía Arauz, 2006).

The main theoretical contribution of this dissertation is the construction of a theoretically integrated optimal scaffolding model (Figure 2, p. 21). The empirical findings of this dissertation provide extensive in-depth evidence for the structure of the scaffolding interactions described in the model, in which the matches and opportunities created by both the teacher and the students proved to be vital. When scrutinizing long-term progress towards learning goals, the empirical findings demonstrate severe challenges in finding an optimal dynamic balance of matches and opportunities at low and high levels. These calibration challenges highlight that the qualitatively different, theoretically relevant levels of participant contributions included in the model are crucial in determining how scaffolding is calibrated during long-term processes. Furthermore, these challenges raise a vital question: **How can optimal scaffolding dynamics become a reality in educational practices, rather than merely an optimistic theoretical goal?** This dissertation reveals that particular care should be taken to strengthen teachers' sensitivity to notice students' learning dynamics and teachers' flexibility to gradually increase the level of the opportunities. Giving up the scaffolding of low achievers should be persistently avoided by experimenting systematically with different evidence-based ways to support low achievers' take-up of the opportunities created.

Based on methodological illustrations of the opportunities created and taken up between a teacher and low achievers, it can be concluded that **SSGs are a powerful tool** for constructing theory and methodologies for representing and analyzing students' learning and teachers' scaffolding as intertwined and dynamic processes. Through dynamic SSGs, it was possible to identify interesting interaction patterns by taking into account, reciprocally, both students' learning and teachers' scaffolding as requested in recent scaffolding research (Gresalfi et al., 2012; Pennings & Mainhard, 2016; Van de Pol et al., 2015; Van Vondel et al., 2016). SSGs are beneficial for both fine-grained analyses of scaffolding dynamics and for scrutinizing the development of micro-level interactions into long-term interaction patterns. The need to understand interactions at both of these levels has been stressed in earlier research (Hollenstein, 2013; Praetorius et al., 2014; Steenbeek et al., 2012).

The studies in this dissertation also highlight that studying optimal and non-optimal scaffolding interactions in the cognitive–metacognitive domain has **great potential for understanding teachers' expertise and the dynamics behind resistance and resilience to learning**. This potential can be applied to help teachers sensitively

monitor and flexibly regulate the dynamics of their scaffolding (e.g. in teacher education and professional development programs). This dissertation's long-term, process-oriented focus provided several crucial and evidenced-based suggestions for developing educational practices by increasing optimal scaffolding (cf. Pennings & Mainhard, 2016). The observed empirical challenges of scaffolding are discussed in this dissertation to provide evidence-based ways of increasing the quality of scaffolding practices, since scaffolding low achievers optimally in complex comprehension and problem solving skills is crucial for helping them meet increasing learning demands at school and beyond (Gresalfi et al., 2012; Haber et al., 2016; Meichenbaum & Biemiller, 1998; Roorda et al., 2011; Vauras, 1991). Our understanding of the effectiveness of long-term scaffolding was deepened through a demonstration of the importance of scrutinizing the levels of matches achieved and opportunities created by teachers and students—not only the learning dynamics of the students emphasized in Study I or the scaffolding dynamics of the teachers emphasized in Study IV. If a teacher is not creating opportunities at a higher level than the students' subsequent participation, then the teacher's scaffolding cannot be effective because it is not creating opportunities for students to achieve matches beyond what would be possible through their unsupported efforts.

To sum up, the methodological, empirical and theoretical progress made in Studies II and III **addresses the need for the development of conceptualizations, analyses, and practices of scaffolding** by capturing the intertwined processes as they unfold over time and at different levels, as requested in recent research (Fischer & Järvelä, 2014; Goldman, 2014; Kunnen & Van Geert, 2012; Van de Pol et al., 2010).

5.3. Nature and evolution of emotional scaffolding

In Study IV, a systematical observation method was developed to gain insight into the nature and evolution of emotional scaffolding. Methodological illustrations were produced by analyzing from videos the emotional support provided by two preschool teachers according the categories developed from self-determination theories (Stroet et al., 2013; Turner et al., 2014; Vansteenkiste & Ryan, 2013) and the Classroom Assessment Scoring System (CLASS, Pianta et al., 2008). At the general level, the developmental findings show that the preschool teachers **provided mainly positive or neutral emotional support and only seldom provided negative emotional support.** Very limited amounts of negative emotional support seem optimal, since earlier studies have revealed that negative emotional support may threaten learning (Roeser et al., 2000; Roorda et al., 2011; Vansteenkiste & Ryan, 2013). In line with in earlier studies (Pennings & Mainhard, 2016; Turner et al., 2014), the findings of this dissertation also demonstrated that it is essential to gain insight into the nature and evolution of emotional scaffolding hidden behind the general level. When the variations in emotional support were scrutinized, interesting differences between and within the

preschool teachers were observed, and both **consistent and inconsistent phases** of emotional support were detected. Consistent phases were considered optimal because earlier studies have revealed that they create safety, strengthen self-esteem and encourage participation (Curby, Brock, & Hamre, 2013; Ruzek et al., 2016). This dissertation's systematic observation also highlighted non-optimal consistency, in which the emotional support became stuck in a continuous oscillation between negative and neutral. From the point of view of scaffolding optimality it is crucial to strive for an increased consistency, which optimally scaffolds learning. It is also pivotal that teachers develop their emotion regulation strategies (Jiang, Vauras, Volet, & Wang, 2016) to limit negative emotional support.

This dissertation's findings demonstrate that preschool teachers display different kinds of developmental profiles. Leena provided more positive emotional support and had more and longer consistent and learning-supportive phases in her emotional support than Petra, whose emotional support was mainly neutral. Leena's emotional support also showed more inter-session variation than Petra's. In the middle session, Leena's emotional support was mainly neutral, while in the beginning and end sessions, it was mainly positive. By contrast, Petra exhibited little positive or negative emotional support across all sessions and even increased neutral emotional support and decreased positive support in the end session. Earlier studies have demonstrated that emotional support should be mainly positive, since this is optimal for learning (Broekhuizena et al., 2016; Curby et al., 2013; Gregory & Korth, 2016; Roorda et al., 2011; Stroet et al., 2013; Turner et al., 2014). Thus, **the dominance of neutral emotional support or the development of positive emotional support into neutral emotional support should be recognized and replaced by increased positive emotional support.** Of especial importance is the provision of positive emotional support when the tasks involve challenges (Fulmer & Turner, 2014). The observations during the analysis of the emotional support emphasize the complex systemic nature of emotional interactions (Pennings & Mainhard, 2016) by showing that the drop in Leena's positive emotional support may have been caused by the difficulty of her questions and the children's shift in attention as they started to drift away from the task. At this point, Leena withdrew to a more neutral approach to emotional support than she exhibited in the sessions where the children participated more enthusiastically and skillfully.

We observed inconsistent emotional support and consistent, harmful-to-learning variations between negative and neutral emotional support more frequently in Petra's scaffolding than in Leena's. Variations in emotional support from one extreme to the other decreased for both preschool teachers in the end session, illustrating the teachers' development in their emotional support regulation (cf. Jiang et al, 2016). Since earlier studies have shown that inconsistent emotional support may cause defiance or withdrawal and tension among children (Brock & Curby, 2014; Vansteenkiste & Ryan,

2013), it is essential to detect and decrease the inconsistency of emotional support to allow children to confidently concentrate on practicing during maximally sustained consistent phases with positive emotional support. Taken together, the findings of this dissertation emphasize **the need to pay increasing attention to emotional support to construct optimal cognitive–metacognitive scaffolding backed up by consistent positive emotional support** to optimally spend the very unique time that can be afforded for scaffolding low achievers (cf. Fulmer & Turner, 2014; Gregory & Korth, 2016; Hamre & Pianta, 2007). The developed emotional support classification offers an in-depth method for recognizing the strengths and weaknesses of teachers' scaffolding in the motivational–emotional domain. Long-term, process-oriented analysis of emotional support provides an important perspective to teachers' expertise and can be applied to help teachers sensitively monitor and flexibly regulate the emotional dynamics of their scaffolding.

5.4. Methodological considerations

As a supplement to the methodological considerations presented in previous chapters, this chapter summarizes the overarching methodological considerations concerning all or most of the studies. One methodological strength of this dissertation was its use of a longitudinal mixed methods approach combining quantitative and qualitative data collection and analytical methods, which allowed us to always select the best methods available to answer the current research questions. This was beneficial because different methods complemented one another in deepening our understanding of scaffolding and learning dynamics at different levels during long-term interventions. In Study I, longitudinal quantitative test data made it possible to determine the effectiveness of the intervention at the group and individual levels. Qualitative observations during the intervention emphasized the importance of scrutinizing scaffolding interactions to deepen our understanding of the on-going calibration of support from both the teacher and the learning environment in optimally scaffolding each student's progress toward learning goals during long-term interventions. In Studies II through IV, the systematic qualitative video analysis formed the basis for the quantitative result summaries and the statistical analysis done to scrutinize the intertwined dynamics of scaffolding and learning. In Studies II and III, dynamic systems methods, representing educational applications of the SSG, were used to scrutinize micro-level scaffolding interactions and their development into long-term scaffolding patterns. In all studies, diagnostic tests of the relevant skills combining qualitative and quantitative analysis methods, were used to select the intervention students. In sum, by combining different methods, this dissertation was able to scrutinize the dynamics of both scaffolding processes and products in the form of students' learning dynamics.

This dissertation also showed that **time scales**, the most appropriate method for tracing the emergence and evolution of learning and scaffolding dynamics, need to

be carefully determined to ensure the most effective use of analysis resources. In Studies II and IV, one session each from the beginning, middle, and end of the intervention (altogether 3 sessions) were analyzed. This analysis made it possible to illustrate the most typical and the most rare observations and to give examples for each. In Studies I and III, the students' learning and scaffolding interaction dynamics were analyzed systematically across all intervention sessions (altogether 26 and 19 sessions). This analysis made it possible to demonstrate interesting developmental patterns, which could have been impossible to capture without following the development of students' learning and scaffolding interactions over an extended time. The importance of doing justice to the intertwined learning and scaffolding dynamics through insights into their development over time has been highlighted in earlier studies (Cash & Pianta, 2014; Mercer & Dawes, 2014; Pennings & Mainhard, 2016; Praetorius et al., 2014; Rojas-Drummond et al., 2013; Turner & Nolen, 2015). This dissertation further demonstrated that students' learning, teachers' scaffolding, and scaffolding interactions fluctuate and form different kinds of short and long developmental profiles and phases. These fluctuations, profiles, and phases illustrate that selecting only certain snapshots at specific times is likely to produce either a more or less optimal picture of the learning, scaffolding, and scaffolding interactions than a systematic observation of all sessions. Naturally, selection based on entire sessions is only one possibility when trying to capture the dynamics of learning and scaffolding.

To address the methodological challenge of capturing intertwined and dynamic scaffolding, all intervention interactions in Studies II through IV were videotaped. Furthermore, participations selected from the perspective of the research questions of each study were systematically analyzed from these videos using the professional computer video analysis programs *Observer XT* and *ELAN*. The **videos and the professional computer programs** proved powerful in capturing scaffolding during the developmental processes, as has been observed in earlier research (Derry et al., 2010; Van de Pol et al., 2010). Specifically the videos and computer programs made it possible to collect in-depth, many-sided developmental process data from complex real-life systems and environments, to return to observations to deepen and extend our understanding of observed aspects, and to carry out reliability analyses of observations. The videos also proved useful in supporting teachers' professional development, since concrete positive examples could be provided in the forms of selected video clips, which could then be confidentially scrutinized to collaboratively reflect on the relevant aspects of scaffolding practices in each intervention group. Such kinds of stimulated reflections have also been shown to be useful also in earlier research (Borko et al., 2014; Pehmer et al., 2015).

5.5. Practical implications

As a supplement to the practical implications presented in the previous chapters, this chapter summarizes the main practical implications concerning all studies. Practical significance is one of the strengths of this dissertation. All of the conducted studies represent attempts to put educational theories into practice, and all were implemented in real-life intervention contexts designed based on the recent theoretical understanding of how to combine optimal teacher scaffolding with powerful learning environments to support low achievers' learning. Furthermore, all studies (apart from Study I) were implemented by teachers scaffolding their own students in authentic learning settings, which increased their practical significance and reliability. Typically, these kinds of theoretically based interventions are implemented by the researchers themselves, which makes changes in the larger educational context unlikely. Most of our teachers continued using the intervention learning environments even after the completion of the intervention research phase as part of their standard support for low achievers, demonstrating that they found elements of the intervention useful. In addition, the first-hand insight drawn from Study I, in which I scaffolded the low achievers myself, proved extremely valuable in all later phases of the dissertation.

The findings of this dissertation emphasize the urgent need to **continue developing researchers' collaborations with teachers** to increase optimal scaffolding. Researchers and teachers should develop together their understanding of more effective ways to integrate educational theory into educational practices to advance optimal multi-domain scaffolding (cf. Turner, 2010). The goal should be to make this collaboration not only one of the most challenging, but also one of the most rewarding aspects of both partners' work (cf. Turner, 2016). When collaborating with teachers to progress towards the optimal scaffolding of low achievers' learning of complex skills, based on the findings of this dissertation, the focus should be on dynamic interactions between teacher and students, as well as persistent multi-domain attempts to achieve an effective balance of matches and opportunities at different levels. Hopefully, this collaboration will reach a stage at which researchers' scaffolding of teachers is so optimal that teachers become brave enough to leave the safety zone of low-level matched interactions and challenge their low achievers.

Powerful teacher education and professional development programs are needed to support teachers' sensitivity with respect to noticing and interpreting typical patterns and critical incidents of students' multi-domain learning processes (Hayden et al., 2013; Myhill & Warren, 2005; Schäfer & Seidel, 2015) and their flexibility in adapting multi-domain scaffolding to students' learning dynamics (Muhonen et al., 2016; Rodgers et al., 2016; Salonen et al., 2005; Vygotsky, 1978). Recent report from the Finnish context (Husu & Toom, 2016) emphasizes that it is crucial to develop effective

and systematic ways to support teachers' professional development, especially in interactions with diverse students, throughout their careers.

The potential of videos in supporting teachers' multi-domain professional development should be developed further (cf. Pehmer et al., 2015). During the studies included in this dissertation, the discussions between the teachers and the researchers on the typical patterns and critical incidents observed in the videos proved to be an excellent way of deepening both partners' understandings of scaffolding interactions. The videos helped to build bridges between the researchers' theoretical perspective and the teachers' practical perspective. Discussing the video data repeatedly helped the researchers support the teachers' take-up of the ideas of optimal scaffolding, particularly when deep changes, and not only superficial changes in multi-domain scaffolding and learning, were noted and reflected in the videos recorded during the intervention (cf. Turner, 2016). As a practical implication of this dissertation, teachers are also encouraged to use videos to systematically observe their scaffolding interactions to facilitate self-reflection. Repeated video-recordings and reflective discussions in researcher–teacher and/or teacher–teacher collaboration can increase teachers' awareness of the levels of their scaffolding dynamics. Identifying attractors and repellors in own scaffolding practices could be an important first step in developing scaffolding skills.

To support teachers in focusing on the crucial aspects of complex multi-domain real-life interactions, **theoretical analysis categories and their practical descriptions** are required. The categories developed in this dissertation for the analysis of strategic level of interactions and teachers' emotional support offer examples of systematic and exact methods for recognizing the strengths and weaknesses of scaffolding and for developing scaffolding continuously into a more optimal direction to support students' learning. Carefully defined categories also enable exact discussions about focused scaffolding aspects in multi-professional teams. Based on their understandings of scaffolding interaction challenges, these teams can consider how each team member can support the teacher and the low achievers in achieving the learning goals. Sharing responsibility for low achievers' scaffolding within multi-professional teams and, if possible, also with parents could be one way to decrease negative affects and teaching-related stress, which can threaten optimal scaffolding of low achievers (Nurmi, 2012; Silinskas et al., 2016).

Teachers also need **systematic long-term learning environments** that are carefully designed based on the recent theoretical understanding of the optimal multi-domain support that low achievers' need to achieve target skills. The intervention environments developed in this dissertation for scaffolding mathematical problem solving, reading comprehension, and listening comprehension are examples of such learning environments. All were designed and implemented in educational practices as part of

this dissertation. Based on the experiences of the research projects, the intervention environments were further developed and then made commercially available for all professionals working in the educational field. However, simply providing new learning environments is not enough. As evidenced by the findings of this dissertation, teachers also need effective long-term professional development programs in order to fully benefit from these new environments. To make a deep change in their scaffolding practices, teachers must update their theoretical understanding and capture the logic and purpose behind the practices in supporting students' learning.

To support teachers in diagnosing students' skills, parallel **tests**, such as the ones developed in Study I, need to be made available for teachers to systematically follow up on students' learning dynamics concerning relevant subskills within and between students (cf. Flynn & Siegler, 2007; Kunnen & Van Geert, 2012). Diagnostic test and evaluation scales developed to identify low-achieving students who have difficulties meeting the current learning goals are also crucial tools for supporting teachers. When standardized tests were not available for the diagnostic purposes of this dissertation, the necessary tests and scales were developed based on earlier research. All of these will be made commercially available. Based on the findings of study I, teachers need to carefully consider how often students' learning should be followed up with tests to capture the relevant learning dynamics within and between students.

To save resources from diagnosis to scaffolding, teachers should find an effective balance between the testing and **continuous observation** of students' learning during scaffolding as ways to follow up on students' progress toward learning goals. The findings of this dissertation call for teachers' skillfulness in using observations on students' progress optimally in their moment-to-moment decision making during scaffolding. Particularly when teachers experiment systematically with different evidence-based ways to scaffold low achievers' take-up of the opportunities created, they are expected to sensitively observe changes in students' participation and learning. To increase teachers' sensitivity and flexibility, teachers need to deliberately practice noticing and interpreting relevant patterns of students' multi-domain learning dynamics and calibrating their scaffolding and support from the learning environment to observations of each student's learning process. Taken together, these findings and practical implications highlight the crucial role of teachers' observational skills in progressing towards optimal scaffolding.

5.6. Challenges for the future

This chapter elaborates challenges for the future based on the limitations of this dissertation. The empirical part of this dissertation relied on systematic in-depth case studies of low achievers' scaffolding and learning in intervention contexts. The theoretical, methodological, empirical, and practical progress achieved in this

dissertation opens fascinating opportunities for analyzing further cases to produce generalizable findings, as well as for applications to scaffolding contexts other than the scaffolding of low achievers' learning of comprehension and problem solving skills. Based on our observations during the counselling sessions, the cases systematically analyzed in this dissertation represent typical scaffolding interactions with low achievers. However, more evidence is needed to make stronger statements of the generalizability of the findings concerning scaffolding of low achievers. Detailed descriptions of the intervention environments and the participants were provided, as requested by Turner and Nolen (2015), so that readers can judge also themselves whether the findings might generalize to other cases. Transcripts of the interactions and still pictures have also been used to give concrete examples of the interaction settings. Hopefully, in the near future, it will be possible to also provide authentic blurred video clips or screen-capture videos of on-going interactions with SSGs, as such tools would be more helpful in demonstrating and interpreting the complex multi-domain interactions than written transcripts alone. Extending this dissertation to other interaction contexts, skill levels, and age groups would increase our understanding of the intertwined, dynamic, and multi-domain nature of scaffolding and learning patterns in different contexts.

The optimal scaffolding model is grounded in the idea of applicability to analyze interactions between **all students and all teachers**. In the future, it is important to collect empirical evidence of scaffolding of average and high achievers. Since high achievers and average achievers can learn more independently than low achievers, they do not need as many scaffolding resources from the teacher. However, when learning goals are too far away even for high achievers and average achievers, these students, too, could benefit from optimal scaffolding. Naturally, the level of teacher scaffolding should always be calibrated to the level of students' practice. Exploring calibration challenges and success would be especially interesting when scaffolding students from different skill levels and age groups. Typically, teachers in different contexts have different opportunities for optimal scaffolding depending on the number and diversity of the students they are expected to scaffold. In this dissertation, empirical evidence was collected from small groups of low achievers in basic education and early childhood education. However, further empirical evidence is needed to investigate calibration in the application of the optimal scaffolding model to the interactions between teachers and students in other contexts.

Scaffolding in classrooms would provide an interesting and highly relevant context for future scaffolding studies, since classrooms are very typical contexts for student learning. Particularly in large classrooms, where teachers must simultaneously adapt to the needs of many individuals (Calder, 2015; Rodgers et al., 2016; Smit & Van Eerde, 2013), teachers need to carefully calibrate their scaffolding to create learning opportunities for each student during every school day. Especially from the perspective

of low achievers, special care needs to be taken to avoid creating opportunities only at too-high levels (though in our small group intervention environments these kinds of opportunities were generally absent). In particular, teachers should systematically follow up those students who do not actively participate in the interactions. Different evidence-based ways to optimally scaffold these students should be carefully experimented to ensure complete student engagement in interactions. Co-teaching (Scruggs, Mastropieri, & McDuffie, 2007) and collaborations among students in small groups might be effective (Iiskala, 2015). Scrutinizing how peers scaffold each other's learning would deepen our understanding of the potential of peer scaffolding in supporting low achievers' learning. This would be crucial in future studies, since Study I and other studies (Iiskala, Kajamies, Vauras, & Lehtinen, 2014; Jenkins & O'Connor, 2003) have emphasized the need to find more effective ways to support the collaboration of low-achievers. Furthermore, results from Study III show that in small group intervention context the low achievers increased important high-level strategic opportunities, but the teachers did not. This could be seen as a sign of the potential embedded in the peer scaffolding during long-term processes.

Studies II and III did not focus on individual students' participation, but, rather, on how the students interdependently, as parts of a group, contributed to interaction dynamics (cf. Granott, 1998; Iiskala, 2015; Turner & Nolen, 2015). However, as Study I indicated, there were interesting differences between and within students' learning dynamics, and these highlight the importance of also focusing on individual students. Further exploring individual students' learning dynamics during scaffolding would deepen our understanding of peer scaffolding and how teachers balance between individuals and groups in their calibration attempts. In future studies, it would also be interesting to combine individual learning outcomes (e.g., grades or test results) and interaction process analyses to advance our understanding of the complex relationships between processes and outcomes of learning.

As a theoretical application of this dissertation, optimal scaffolding models could be constructed to analyze scaffolding interactions aiming for **other learning goals** than reading comprehension. Then, the model constructor would need to define the theoretically relevant, qualitatively progressing levels of achieving the learning goals and how these are operationalized for each participant in the scaffolding context of interest for the constructor. Defining levels as off-goal, pre-goal, goal, and meta-goal levels as was done in this dissertation, could be one starting point. Constructing this kind of a model could deepen our understanding of the dynamics of matches and opportunities created by participants at different levels of achieving a diversity of learning goals. Furthermore, SSG methods could be used in these future studies to represent and analyze interactions in these new learning settings. SSG illustrations and time-series figures could also help to support teachers' professional development by directing attention to vital patterns observed during interactions.

In this dissertation, students' learning and support from both the teacher and the learning environment were considered as the three intertwined wheels of scaffolding interactions (Figure 1, p. 20). The calibration of the support from the learning environment was included at the general level in all studies, in that the implemented interventions were carefully designed to be calibrated to the needs of low achievers. While scrutinizing the calibration of teachers' support in Studies II and III, the teachers' continuous calibration of the learning environment to the needs of low achievers was also involved. The systematic analysis showed that teachers faced challenges calibrating both their support and the learning environment to the needs of the low achievers. Observations further showed that teachers continuously calibrated learning environment support by selecting which goals and tasks to include in their scaffolding and the amount of effort and time to devote to their selected goals and tasks. Sometimes, teachers left out high-level lesson goals or simplified high-level tasks so much that they demanded only decoding skills from the students. The calibration of the support also typically failed on high-levels, resulting in a failure to achieve learning goals. Sometimes when the teacher support wheel slowed down or stopped turning, the only wheel that tried to continue was the wheel of the students' learning. In future studies, therefore, it would be interesting to scrutinize the calibrations of the support from the environment and the continuous calibration of the environment by the teachers. This would deepen our understanding of the potential for environmental support, such as through a computer-supported learning environment as a scaffolding tool (cf. Puntambekar & Hübscher, 2005) to help save human resources.

Also in future scaffolding studies, both teachers' scaffolding and students' learning should be systematically analyzed to reveal matches and opportunities created by the interaction participants. If only one participant is focused and the other participant is more or less left out, conclusions concerning the calibration of scaffolding can merely be speculative. Because careful calibration is the core of typical scaffolding definitions (Muhonen et al., 2016; Steenbeek et al., 2012; Van de Pol et al., 2014; Wood et al., 1976), speculations are not enough, but insights into calibration processes of scaffolding interactions are crucial. If the care with which the teacher's support is calibrated to the students' learning is unclear, using the term 'teacher's scaffolding' should be avoided, and a wider term 'teacher's support' should be used. More empirical research on the dynamics of optimal scaffolding is also needed. For example, how should matches and opportunities created by teachers and the students be calibrated to secure optimal multi-domain scaffolding during extended processes, and how this optimality depends on dynamic systemic elements, including, particularly, learning goals, environment, and interaction participants?

Interviewing teachers about their reasons for participating at certain levels would further deepen our understanding of their perspectives on scaffolding and students' learning. It is particularly vital to understand why high-level opportunities are created

and/or taken up or not. Furthermore, it would be valuable to know what changes teachers observe during and after long-term interventions in both their scaffolding and students' learning. In particular, Eeva later reported that she deeply understood the goals of the intervention only when she continued using the environment after the research phase. Scrutinizing the development of scaffolding interactions during repeated implementations of the same intervention environment would provide an interesting understanding of the stability and dynamics of teachers' expertise, while also revealing challenges and potential achieving deep changes in educational practices (cf. Rodgers, 2016).

If the calibration of teacher support and the effectiveness of scaffolding in supporting students to achieve goals beyond what would be possible through their unsupported efforts prove to be as challenging as they were in this dissertation (and as they have typically been shown to be in other earlier studies), the definition for scaffolding should be modified. A more adequate characterization for scaffolding could be: Teacher support that **aims to** be carefully calibrated to create opportunities for students to achieve goals beyond what would be possible through their unsupported efforts. This definition would still preserve the ideas of careful calibration and high-level goal achievement, which are not so heavily emphasized in, for example, close relative words, such as teaching and instruction. However, it would not place such strong requirements and guarantees on the optimality of calibration and its effectiveness in supporting student outcomes that are, in educational practices, pivotal, but challenging to achieve. The adjective 'optimal' could still be added before 'scaffolding' to describe how scaffolding has proven to be carefully calibrated to students' learning.

Particularly, rigorous longitudinal studies on the dynamics of multi-domain scaffolding interactions are needed to deepen our understanding of the calibration challenges. It is also vital to develop theoretical models and analytical tools to capture the complexity of multi-domain real-life teacher–student interaction dynamics **simultaneously** in the cognitive–metacognitive and motivational–emotional domains of scaffolding and learning. This would further deepen our understanding of scaffolding interactions and their consequences for the systemic formation and maintenance of learning dynamics. In these future studies, the goal would be to unpack the general metaphor of the zone of proximal development (Vygotsky, 1978) with more precise cognitive, metacognitive, motivational, and emotional descriptions of the optimal dynamics of teachers' scaffolding and students learning. We have begun this work and presented interesting preliminary results of these many simultaneous layers of analysis in a symposium presentation (Kajamies, Vauras, Lehtinen, & Kinnunen, 2014).

In closely scrutinizing the evolution of intra- and inter-system stability and variability in Study III, we observed short developmental phases, fluctuations, and intertwined dynamics. These kinds of patterns can be educationally interesting (Broza & Ben-

David Kolikant, 2015; Kunnen & Van Geert, 2012; Turner et al., 2014; Vallacher et al., 2015). However, the reasons these patterns showed unsustained optimal development must be explored in future studies. Furthermore, crucial moments of interactions could be taken as a starting point for the analysis to deepen our understanding of the dynamics behind different kinds of patterns. In our analysis, we used the **Lag Sequential Analysis** (LSA) of Observer XT to carefully examine how multi-domain participations evolved around students' strategic participations, which are considered to be critical moments in practicing reading comprehension strategies (Kajamies, Vauras, Volet, Lehtinen, & Kinnunen, draft). The LSA is used to calculate the frequency and probability of participations preceding and following students' strategic participations, which could deepen our understanding of the evolution of typical teacher and student participations before and after these critical moments. Furthermore, the LSA reveals how teachers and the student/s participate in the creation and taking up of these critical moments, thus further deepening our understanding of the intertwined, dynamic, and multi-domain nature of scaffolding interactions.

6. References

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