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"This is the size of one meter": Children's bodily-material collaboration

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Abstract In CSCL studies, language is often foregrounded as the primary resource for engaging in collaborative learning, while the body is more often positioned as a secondary resource. There is, however, a growing interest in the body as a resource in learning and collaboration in and outside CSCL. In this paper, we present, analyse, and discuss how two nine-year-old children collaborate through gesturing and moving their bodies around a touchscreen. The pair is working with the concept of scale and area measurement and are in midst of copying their rooms from paper to touchscreen. During this process, the pair engages in a discussion regarding the size of one meter through language, gestures and manipulation of the material resources. The analysis shows two distinct ways of understanding the length of one meter, which primarily are visible through the children's gestures and bodily movements. In the analysis we show how the children dynamically produce body-material resources for communicative and illustrative purposes; moreover, they use body-material resources as a cognitive tool and as a way of shepherding each other. The study forms part of a body of studies analysing and theorizing the body in education, learning, and interaction. We discuss the wider impact of our findings and argue how they may challenge and improve studies relying mainly on a coding and counting approach or automated capture of e.g. gestures. In addition, we provide a detailed multimodal representation of the subtle bodily-material resources, which we argue is a modest contribution to a catalogue of ways of representing and making bodily-material resources visible in CSCL research. Q1

Keywords Bodily-material resources for learning · Embodied meaning-making practices · Touchscreens · Video analysis · Concept of scale · Embodied interaction · Knowledge building

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> "When the proportions of architectural composition are applied to a particular building, the two-termed relationship of the parts to the whole must be harmonized with a third term—the observer. He not only sees the proportions of a door and their relationship to those of a wall (as he would in a drawing of the building), but he measures them against his own dimensions. This threetermed relationship is called scale." (Britannica Online Encyclopedia, 2014).

Introduction

While already Vygotsky (1978, 1986) argued that gestures and body movements play a central role in children's communication, learning, and development, it seems equally evident that even in Vygotsky's own work, language is considered the primary vehicle for learning, communication, and collaboration. Since the time of Vygotsky's work, the body has occasionally been positioned as central in learning processes. However, there has been a tendency to privilege embodied experiences as means for developing concepts and language in the mind (e.g., Niebert et al. 2012). Nevertheless, recent work has emphasized that learning is haptic, kinaesthetic, visual, and spatial, rather than purely verbal and linguistic, or logical and mathematical (De Freitas and Sinclair 2014; Jornet and Roth 2015; Lindwall and Ekström 2012). Likewise, within CSCL we would argue that language and tools (artefacts) have until recently been considered the most important resources to study in relation to learning, communication, and collaboration. It should be mentioned, however, that classical studies in CSCL, like Roschelle and Teasley (1995), were oriented towards the role of gestures, gaze, and body movements in collaborative activities, without theorizing them in their own right. We definitely do not wish to dispute the central role of language and artefacts in collaborative learning, but we would like to emphasise the crucial role of gestures and body movements as bodily-material resources which are important in relation to communication, learning and, collaboration.

In this paper we present, analyse, and discuss a short video excerpt (66 s) of two nine-year-old children's interaction, learning, and collaboration around a touchscreen. In the video excerpt, the children are working with the concept of scale, which is understudied in mathematics education (Jones and Taylor 2009). The excerpt is a small clip from a larger set of data (video, interviews, and classroom observations) from a long-term research process and collaboration with a particular school over an entire school year. While we return to the context of the data, the main purpose of this paper is to use a small example to illustrate and theorize what role the subtle details of the bodily-material resources play in children's collaboration around touchscreens. We discuss how bodies and gestures are used as communicative/illustrative, cognitive, and collaborative resources, and we show how they are dynamically used to organise intra- and inter-psychological processes (Vygotsky 1978). In the example the children are working with the concept of scale using graphing paper on both paper and touchscreen, and we trace how they use language, posture and gestures to convey and negotiate their understandings of this concept. Further the analysis confirms Jornet and Roth's (2015) argument that understandings of concepts are structured and accounted for by bodies operating on them in the local situation. We argue that they use the bodily-material resources as 1) a communicative and illustrative resource for showing each other their understandings, 2) a cognitive auxiliary tool scaffolding knowledge building, and 3) a way of shepherding

(Cekaite 2010) and instructing each other. Further, we discuss how we view this as particularly relevant to the (re)growing interest in co-located collaborative environments (Higgins et al. 2011) within CSCL and a more general interest in the role bodily-material resources play in learning, interaction, and collaboration (Alibali and Nathan 2012; De Freitas and Sinclair 2014; Jornet and Steier 2015; Jornet and Roth 2015; Lindwall and Ekström 2012; Majlesi 2014). Thus, our study forms part of what could be termed the bodily turn in learning and within CSCL, and adds to our current understanding of learning, interaction and collaboration by explicating the intricate ways bodily-material resources are used in meaning-making practices. In brief, the interest in co-located collaborative settings and bodily-material resources has been instigated by the technological development of various multi-user technologies and more 'natural user interfaces' (Kirsh 2013), such as tabletops, tablets, tangible interfaces, and interactive whiteboards. Among other things, the possibility for several users to touch and manipulate objects on the screen simultaneously has been highlighted as a major benefit for collaborative learning (Hornecker et al. 2008; Rick et al. 2011; Sakr et al. 2014). Furthermore, some researchers have argued that the possibility to touch is a more direct form of interaction than interaction through keyboard and mouse (Hornecker et al. 2008). While direct interaction on the screen with others is an important aspect of touch technologies, we argue that the zone in-between children and touchscreen offer new conditions for children's bodily-material communication, collaboration, and learning, which are equally important to understand in relation to the bodily turn in learning and collaboration.

We initially focus on the bodily turn in learning and collaboration, after which we outline our theoretical and methodological orientation of interaction analytical studies. This is followed by a review of related work on collaborative learning around touchscreens. We then present the short video excerpt, and subsequently we analyse, interpret, and discuss the wider implications of our analysis for CSCL.

The bodily-material turn in learning and collaboration

Goodwin's pioneering work on embodied interaction (1981, 1994, 2000, 2007, 2013) has influenced many of the recent studies which are aiming to make visible the bodily-material resources participants use in learning, instruction, and collaboration (Davidsen and Christiansen 2014; Jornet and Roth 2015; Hindmarsh et al. 2011; Lindwall and Ekström 2012; Majlesi 2014). With the concepts 'contextual configuration' and 'semiotic resources' (Goodwin 2000), he showed how participants in different settings act on and with the local resources made available by the participants in the situation. They co-operate by building on and inhabiting each other's interactions and bodies (Goodwin 2013). In his studies of archaeologists, Goodwin (2007) also pointed out that gestures are not universal, but that they are closely coupled to the environment. By suggesting that gestures are environmentally coupled, he argues that we should focus on the production of gestures in the specific environment for a particular communicative or illustrative purpose, rather than treating gestures as iconic, metaphoric, deictic or beat. Likewise, from an anthropological perspective, Ingold (2015) in his recent book eminently formulated why we should scrutinize the role of hands in human interaction: "(…) hands are the means of togetherness. That is, they are the instruments of sociality, which can function in the way they do precisely because of their capacity – quite literally – to interdigitate" (2015, p. 6).

Following and contributing to the tradition of embodied interaction analysis, Koschmann and LeBaron (2002) showed how learner articulation depends on multiple interactional resources and concluded that gestures “are material signs that embody the knowledge being articulated while simultaneously shaping and lending structure to social interaction” (p. 271). In a more recent study, examining student’s sense-making practices in a technology rich setting, Jornet and Roth (2015) argued that students’ bodily engagement with materials, representations and objects serves as a way of “developing vernacular language towards other forms of discourse and representations” (p. 397). This confirms Roth’s (2002) previous work on how children first master a concept in gestures and later learns how to ‘talk the talk’ of scientific language. Jornet & Roth (2015, p. 395) further formulated that “The means by which such phenomena were structured and accounted for appeared inseparable from the bodies acting on them” which aligns with the perspectives formulated by Goodwin (2013), Koschmann and LeBaron (2002), and Streeck (2009). These researchers have in different ways argued that gestures and body movements are dynamic actions that cannot be separated from the local environment and present semiotic resources. Further Streeck (2013) suggested that rather than treating bodily intersubjectivity as a purely linguistic and visual phenomenon we should consider tactile and kinaesthetical elements of embodied interaction as equally important for displaying and building knowledge together.

The role of language and body in the history of CSCL

In CSCL, language (written text and spoken utterances) and artefacts are viewed as the primary resources for engaging in collaborative learning activities online, face-to-face, or in blended learning environments. Stahl argued that “*meaning is created across the utterances of different people*” (2006, p. 6 italics in original), and in a recent overview of CSCL Dillenbourg et al. (2009) stated that language is believed to be the primary resource for engaging in collaboration. Text (like other physical objects) is also considered as an artefact in the CSCL community, which can embody meaning or facilitate intersubjective processes of meaning-making (Stahl et al. 2014). CSCL, as a scientific community, has developed methodological and theoretical rich vocabularies for analysing and discussing the role of language in collaborative learning.

While language has been of primary interest in many CSCL studies, there has been a growing interest in bodily aspect of learning and collaboration. At CSCL 2015 in Gothenburg, the bodily-material turn was described as an inevitable direction for CSCL to pursue in the future – partly instigated by an overall interest the body in learning, philosophy, cognitive studies and interaction studies, and partly due to the technological development towards more natural user interfaces (Lindwall et al. 2015). A conceptual study by Flood et al. (2015), addressed the importance of embodied performances for learning and communication between learning scientists and computer scientists and also described the difficulties in making visible embodied interactions in representations and transcriptions for different professions to examine. In the neighbour field of Human Computer Interaction (HCI) Xambó et al. (2014) termed the interest in embodied computer interaction as ‘third-wave HCI’. Thus, there is a more general turn towards the body in learning and collaboration beyond the field of CSCL. It seems crucial, however, that CSCL play a role in analysing, theorising, and designing for embodied computing across the domains of CSCL.

In the history of ijCSCL embodiment and embodied interactions have been addressed in several ways: 1) Body language (Dwyer and Suthers 2006) and gestures (Szewkis et al. 2011) can show signs of awareness between group members and student thinking (Ares 2008). 2) A problem space, practice or discourse is continuously negotiated and established through talk and gestures (Herrmann and Kienle 2008; Kershner et al. 2010; Krange and Ludvigsen 2008). 3) Bodily orientations, such as gestures, eye gaze, etc., are part of supporting the multimodality of embodied interaction (Perit Çakır et al. 2009). 4) The body is used as means for elaborating the artefacts under scrutiny, for example, to highlight, suggest, formulate or describe (Lymer et al. 2009). 5) Gesturing is crucial in establishing mutual alignment between the participants (Lymer et al. 2009). 6) Participants use gestures and language to communicate and develop concepts (Gómez et al. 2013) and "indexical ground for future interactions" (Evans et al. 2011, p. 274). 7) Wegerif (2006) argued that reasoning can be located in embodied interaction. 8) Practices, artefacts, materials and physical tools can embody socially constructed knowledge and concepts, which can function as mediating artefacts for individuals and groups (Arvaja 2007; Hakkarainen 2009; Muukkonen and Lakkala 2009; Öner 2008; Ritella and Hakkarainen 2012; Stahl 2010; Yukawa 2006). 9) Embodied learning is a way of expressing the role of the body in education (Birchfield and Megowan-Romanowicz 2009). 10) Predictions and understandings of the participants are embodied (Enyedy et al. 2012). 11) Gesturing and body movements play a central role in establishing and negotiating shared understandings of problems (Greiffenhagen 2011; Stahl and Hesse 2006). 12) Bonderup Dohn (2009), taking a phenomenological stance on CSCL, argue that interaction should be viewed as a bodily phenomenon, yet, Bonderup-Dohn only provided a theoretical understanding of the body's interactional and cognitive potential.

All of these studies suggest that gestures, body movements, and language play a central role in computer supported collaborative learning. However, it is also evident that the community needs to find better ways of addressing, analysing, and theorizing bodily-material resources in learning and collaboration. Already, Roschelle and Teasly (1995, p.79) argued that "… actions and gestures likewise serve as presentations of new ideas" in their study of computer mediated collaboration. Thus, there has been an interest in the affordances of bodily-material resources for collaborative learning in the community of CSCL, but the prevalent idea is that language is the primary vehicle for collaboration and meaning-making between the participants.

Making bodily-material resources for learning and collaboration visible

Making bodily-material resources for learning and collaboration visible requires careful consideration in terms of selecting a suitable form of representation. Flood et al. (2015) note that presenting embodied interaction is a challenging activity in CSCL studies. Several studies in CSCL on bodily-material resources are informed by ethnomethodology (EM), conversation analysis (CA), and socio-cultural theories of learning. Studies inspired by EM and CA have shown some of the ways gestures and body movements facilitate collaboration and problem solving, while the studies informed by socio-cultural theories of learning highlight the social and cognitive potential of gestures in learning and collaboration. With the recent and (re)growing interest in bodily-material resources for learning, there is a need to find and develop ways of showing how bodies, materials, and technology intermingle in learning and collaboration which moves 'beyond unproductive generalisation' (Lindwall & Lymer 2005, p.394). Q3 Thus, as argued by Sheets-Johnstone (2011), we need to move beyond "think(ing) in monolithic compartmental wholes: eating, mating, courting, defending, aggressing, threatening, and so on; it is to think in dynamic terms – in terms of speed, postural orientation, range of movement, force and direction and so on". (p. 442). While annotation systems for body

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movements exist, none of these co-exist well with verbal elements, and Flood et al. (2015) argue that we need to establish a system for "representing and cataloguing choreographies of embodied interaction" (p. 96). However, a unified or universal system might not be something to strive for, as the interaction and context demand different ways of representation to highlight and support the argument of the researcher (Luff and Heath 2015). In CA, the language bias is also discussed by Ayaß (2015), who argues that visual and bodily details are often added to the transcript of verbal utterances. In many cases, embodied actions are also conformed to the affordances of written language, which does not do justice to the sequential and simultaneous unfolding of embodied interactions. Thus, a strict focus on talk in transcriptions and representations may be counterproductive to advancing theories of embodied learning and collaboration. Q4

In order to analyse how children use their hands and bodies as resources for engaging in collaborative learning, we have applied embodied interaction analysis (Streeck et al. 2011) to a short video excerpt (66 s of interaction). Embodied interaction analysis does not prescribe one way of doing analytical work, instead it focuses on what the participants treat as relevant and "recognizes the diversity of semiotic resources used by the participants in interaction, and takes into account how these resources interact with each other to build locally relevant action." (p. 2). Thus, rather than assuming language as the primary resource for collaborative learning, we focus on a triad of constituting semiotic resources; language, body and material resources. We use the video excerpt as an illustration of the importance of understanding children's gesturing and bodily collaboration around and on touchscreens, but also in the zone in-between. This opens an opportunity to understand and theorize children's embodied (bodily-material) methods of communicating, collaborating, and learning in CSCL settings, e.g. how they use their hands and bodies as a means of producing situated and locally relevant understandings and as a means of thinking together around touchscreens.

Related work - touchscreens and CSCL

Within the past 15 years, the CSCL community has been active in designing for and understanding collaborative learning around multi-user technologies, like tabletops and interactive whiteboards (Davidsen 2014). This forms part of what Higgins et al. (2011) characterised as a reorientation to collaborative learning in co-located settings. Some of the studies on tabletops revolve around one of the basic research traditions in CSCL identified by Stahl et al. (2006); namely experimental laboratory studies. In this paper, we briefly examine the experimental studies to review some findings, methods and theories found in the body of related studies on collaborative learning around touch technologies in order to situate our work within the traditions of CSCL research. In addition, we present some of the studies focusing on the opportunities touchscreens provide for bodily-material learning.

Laboratory and experimental settings

Some of the general traits of the experimental studies are; laboratory settings, restricted/limited time frames, selected user groups and hypothesis testing. Based in these laboratory experiments researchers have provided important findings on children's collaboration around tabletops; for instance, Harris et al. (2009) reported that children talked more about turn taking using single-touchscreen and that children were more task oriented in a multi-touch setting. In this experimental study, the children were told to produce a seating plan for their classroom based on information about the different groups of pupils. Harris et al. (2009) tested the tabletop for a short period of time in the classrooms and concluded that the children were excited to work with the new technology. Rick et al. (2011) suggested that enforcing equitable physical participation can disrupt the dynamics of collaborative learning. This was based on work with three pairs working with DigiTile in the back of a classroom in 30-min sessions. The researchers instructed the children on how the tabletop functioned and then interviewed the children during the sessions. Rick et al. (2011) subscribed to some of the common understandings about the affordances of interactive tabletops: in particular, awareness of each other's actions and concurrent, parallel work. Finally, Higgins et al. (2011) stated, based on the quantity of touches and the types of utterances, that multi-touch tables support collaborative interaction more effectively than the paper-based version of the task (e.g. a joint problem space in collaborative learning tasks).

Coding and counting of interaction

Another common characteristic of the experimental studies is the methodological orientation towards coding and counting children's interaction by applying different theoretical models. For example, Mercier and Higgins (2014) applied two coding schemes; one for determining levels of reasoning and one for determining tabletop use (direct touches on the surface). By separating levels of reasoning and tabletop use, however, Mercier and Higgins enforced a split between language and body movement. The separation of language and movement might be a fruitful analytic distinction, but as we shall show in the analysis, this can potentially leave out subtle details of the interconnections between thought, language and bodily-material resources in children's joint reasoning and collaboration. As observed by Vygotsky "Communication without action remains unintelligible (…)" (1986, pp. 52–53) for the child, and we suggest that these relations are important to scrutinize more carefully in CSCL. Furthermore, we also argue that although 'direct touches' on the touch-screens are obviously important, it is equally important to understand bodily interaction and gesturing in the zones in-between the touchscreens and the children. As we will show this zone is important in terms of communication, collaboration and learning.

Automated capture of multimodal interaction

Martinez-Maldonado et al. (2013) acknowledge the importance of nonverbal and verbal interactions in co-located collaborative learning activities. As a consequence, they developed a system for automatically capturing talk and physical actions (touches on the screen) on a multi touchscreen with video equipment, screen capturing software and a 3D body scanner. Based in the data generated from this complex data capture system, the authors pointed out that "the less collaborative groups had a predomination of patterns with physical interactions, high levels of physical concurrency and greater parallelism than the more collaborative groups." (p. 481), while "…the more collaborative groups had more verbal discussions in conjunction with physical actions…" (p. 481). These results, which are based on the automatic collection of numbers and statistics, are meant to help teachers in obtaining and scaffolding children's collaborative activities. With an interest in understanding the role of the hand, Sakr et al. (2014) address the affordances of touchscreens to support multimodal and embodied interaction and learning. In particular, the authors scrutinized the role of hands and tried to develop a taxonomy of hand movements around tangible interfaces. Compared to some of the other studies above (e.g., Martinez-Maldonado (2013)), Sakr et al. (2014) acknowledge that it is not only interesting to count the number of touches on the surface, it is equally important to understand what the hands are doing in the space-in-between the students and the students and the technology. In a similar vein, Davidsen and Christiansen (2014) conclude that children use their hands "to constrain and control access, to construct and problem solve, and to show and imitate" (p.34) around touchscreens. Recently, Blikstein and Worsley (2016) argued that Multimodal Learning Analytics can provide new insights into the nature of learning compared to traditional research methods and list in their review how studies have captured gaze, posture, gestures and more. For example, they discuss how students' posture - and the transition between different postures – affects learning. Thus, there is an increasing interest in capturing, analysing and theorizing the bodily-material resources for learning around touchscreens, which the analysis in this paper contributes to.

The "Move and Learn" project: two children working with the concept of scale

The "Move and Learn" project was a technology integration project initiated by a Danish public school where two classrooms were physically re-organised with 16 single-touch screens and two interactive whiteboards.[1] The overall aim of the project was to explore how touchscreens can support multiples ways of learning, e.g. "auditory, visual, tactile and kinaesthetic approaches" (Davidsen and Georgsen 2010). During the school year the children were instructed to work together in pairs around the touchscreens (the children would rarely work individually with the technology). The teachers decided the combination of the pairs and tried out different combinations during the school year, which was based in the video feedback sessions facilitated by the researchers (Davidsen and Vanderlinde 2014). The school invited researchers (one being the first author) to follow the process and to act as discussion partners to the teachers. Throughout a school year two researchers followed and worked with the school (Davidsen and Georgsen 2010) and collected data in a variety of ways (e.g. 150 h video material, observations, interviews with teachers, children and parents, and screen-recordings). In each of the classrooms, three video cameras were installed above three different screens. Besides using fixed cameras the research team also used small camcorders to capture interaction from other angles. In the example we present and analyse in this paper, the children and teachers had been working with the single touchscreens in their classrooms for about nine months and therefore had some experience in working together in front of the touchscreens.

The learning material

The concepts of scale and area measurement are central in math education (Jones and Taylor 2009; Kordaki and Potari 1998). Nevertheless, we are only starting to develop understandings of how children learn about scale (Jones & Taylor, 2008). Lock and Molyneaux (2006) note that the concept of scale is easy to define, but often it is a difficult and slippery concept to grasp, and studies indicate that few children are able to understand it before the age of eleven (Gaite 2013). In the example we analyse the children are learning about the concept of scale

[1] Names of each child, teacher and the school have been changed to secure their identity.

and area measurement together in front of a touchscreen. The pedagogical ideal of the teacher(s) is that students learn better together. The example stems from the final period of the "Move and Learn" project. The teacher had designed learning materials where the children were to collaborate on an assignment regarding the concept of scale and area measurement (see Fig. 1). As a final outcome of the children's work with the concept of scale and area measurement they were to produce a video story about their own room at home by using screen recording software. This should illustrate both their individual and collective understandings of the concept of scale and area measurement. The task involved two overall steps. First each child had to measure and draw their private room from home on traditional squared paper. Secondly, they had to draw their rooms together with a classmate using the touchscreen and the grid made by the teacher. While sitting together, the children had to go through three steps (see Fig. 1): 1) Draw their respective rooms on the touchscreen together, 2) position the relevant objects (provided by the teacher) in the room and 3) finally record a multimodal story about their own room. Thus, the children are working with multiple representations and tasks to learn about the concept of scale and area measurement.

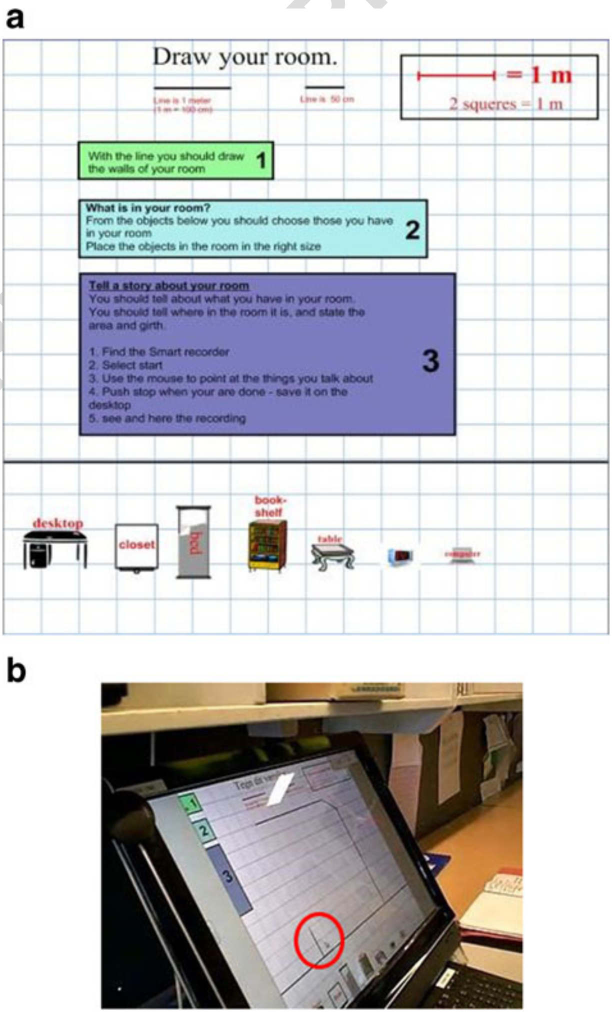


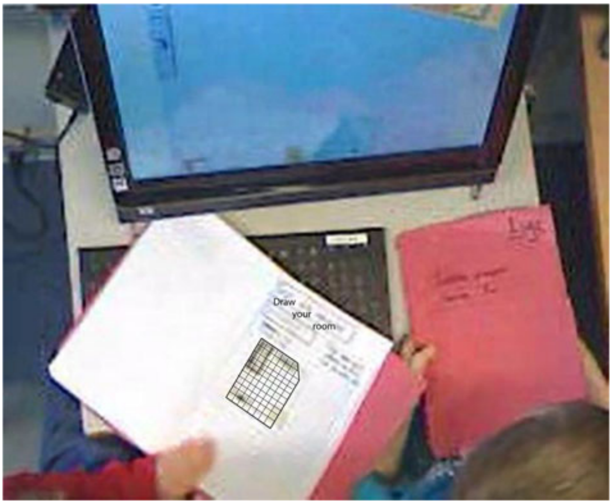
Fig. 1 **a** top + (**b**) bottom. Learning material + picture from actual screen (*red circle* is our addition)

The workspace on the touchscreen is illustrated in Fig. 1a + b below. Figure 1a is a reconstruction of the screen where we have translated the three task formulations from the teacher. Figure 1b is an actual picture of the screen. On the screen in Fig. 1b the three tasks are placed 'out of view' towards the left of the screen. From here the children can 'drag' them into view and then 'drag' them out of the screen again. In Fig. 1b one can further note they have already begun their work, and have placed different lines (apart from the bottom horizontal line which was there as part of the teacher's setup). The children add new lines by dragging a copy of either one of the lines just beneath the heading 'Draw your room.' (Fig. 1a) and then - if needed - rotate the line to become vertical (or diagonal). In Fig. 1b we have added a red circle around a 2 square vertical line. The placement of this particular line is the children's main concern and activity in the situation we analyse.

Hence, the learning material designed by the teacher serves as an action- and information-space (Bamberger 1991) for the children (Fig. 1). It functions as an information-space that provides information about the units (two squares are equal to 1 m) the children should use to solve the task and it also contains a description of the tasks. In addition, it also serves as the space for action where the children should calibrate and position the lines (walls) according to their drawings on paper (Fig. 2) and move the pre-produced furniture to the correct position in their individual rooms.

The design of the tasks did not prescribe how the pairs were to collaborate. Hence, the children had to negotiate this continuously throughout the activity. While the task of converting their drawings from paper to screen was 'just' copying from one medium to another the children's translations from paper to touchscreen provide a demonstration of their individual and collective understandings of scale and the size of one meter (Fig. 2). Although the task seems straightforward, the children have to adjust their understanding of scale based on the size of the squares on the graphing paper and on the screen. While they are not consulting the leaflet as a resource for their collaborative activity in this situation, it is a much-used resource in other moments. For instance, if they are in doubt or if Peter questions Nathalie's drawing they consult the drawing on paper. The drawing on paper also act as a way of controlling the other's access to the information-space, as they put away their personal leaflets on the table next to them – out of reach of the other child.

Fig. 2 Drawing in Nathalie's leaflet



Data handling and transcription

The children worked with the task in 5 sessions of 45 min distributed over a week. In total, 11 h and 17 min of video footage were recorded with three different pairs working with this learning material. On this basis, we selected one situation (66 s) to illustrate how the children use bodily-material resources for communication, collaboration and learning. In the example we follow Natalie and Peter, who are both nine years old. At that point in time, Nathalie and Peter had been working together for three weeks. Prior to this week, they were working together on producing a multimodal story about Good Friday (Davidsen and Christiansen 2013). Similar to the rest of the pairs in the classroom they have been working with the overall task for one week, and in the particular situation they are in the midst of transferring Natalie's room from paper to screen.

The situation was first transcribed using Transana (Woods and Fassnacht 2015) and then ELAN (Max Planck Institute for Psycholinguistics 2016). In Transana, the overall collection was coded to identify which pairs were working together and the subject of the specific period. A basic transcript was also produced in Transana before a detailed transcription was produced in ELAN. The particular layout of ELAN enables an "unnatural" separation of talk, gestures, and body movements. However, for the purpose of analysing the complex data, the multi-layered transcription offers a view on the simultaneous production of gestures, body movements, and talk in front of the collaborative infrastructure. After the children's language and bodily movements were transcribed, we selected 26 snapshots which were redrawn using Adobe Illustrator. The process of selecting these snapshots was informed by our interest in studying bodily-material resources for learning and collaboration. However, the production of the snapshots was a selective process – where the individual snapshots were evaluated based on how well they communicated the subtleties of the embodied interaction. Also a frame-by-frame representation in snapshots would take up many pages and we decided to include snapshots where the children change body position. Thus the selection is based on our theoretical interest and previous work with the data – we are interested in finding ways of presenting the complex, sequential and simultaneous play between body, language, and material in the transcripts. As argued by Davidson (2009) a transcript should reflect the decisions made by the author to highlight and augment the analysis. The transcription format developed in this paper could form part of a catalogue of 'choreographies of embodied interaction' in the community of CSCL.

Analysis

Children demonstrating their understandings of one meter and the concept of scale

Below, in Figs. 3, 4, and 5, the chronological development of the children's activity is represented with cartoon-like transcripts (e.g. speech bubbles and "pencil drawings") based on the original video footage. With this situation, we want to illustrate different aspects of the children's ways of using gestures and movements as part of their collaborative activities, e.g. as a communicative and illustrative resource, as a cognitive tool, and as a way of shepherding and instructing each other. Following the presentation of the children's activity, we analyse and discuss the findings in relation to CSCL and from a theoretical and methodological perspective. In our descriptions and analysis, we refer to the numbered pencil drawings and the children's talk as frame 1–26.

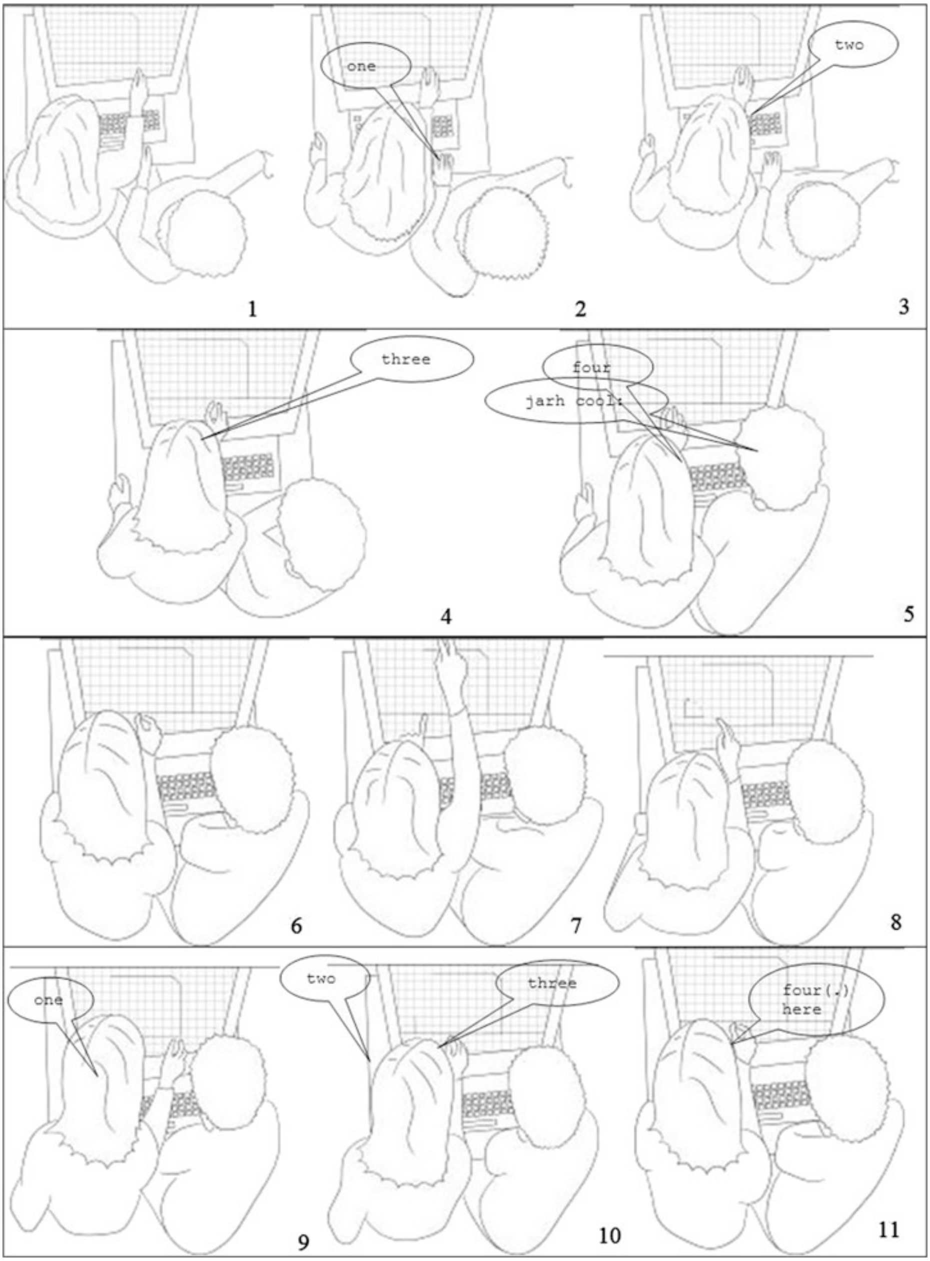


Fig. 3 Transcript 1

However, we initially will give a brief narrative account of what happens throughout the clip. We provide this initially to give the reader a better idea of what is unfolding in the situation, and to help in the reading of the transcripts and the more detailed explanations. This is not a neutral description, but rests on our analysis of the data, and thus reflects what we see as the overall important features of the situation. The whole clip concerns Natalie trying to

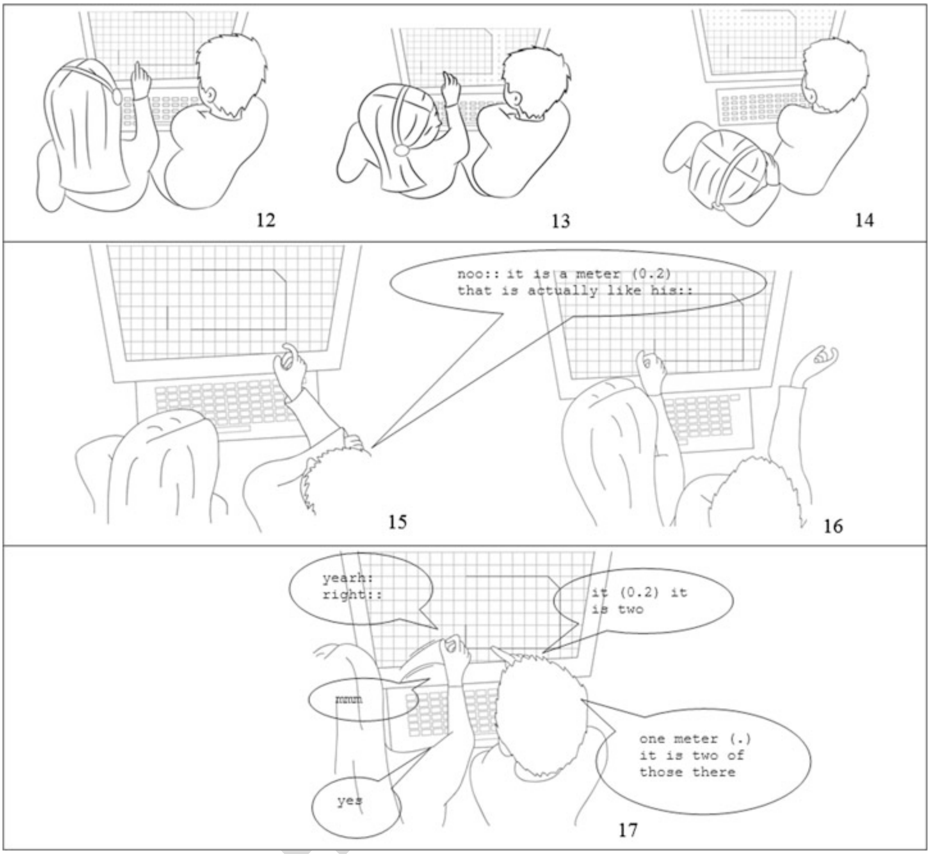


Fig. 4 Transcript 2

place a 2 square vertical lines in the right place to act as the final wall for her 'room'. In Fig. 1b the line is placed correctly, and act as the first line to building the final wall of her room.

Narrative: [Transcript 1] Natalie has just returned from a desk that is outside the view of the camera. Here she was consulting a scaled paper drawing of her room and we can hear her count. As she comes back she starts to count (one, to, three, four) – she stops at four (which is 8 squares) and uses a finger to mark the spot where she should place a vertical line (which is the correct place). She then tries to drag down a small horizontal line. However, as it is a single-touch screen she has to remove her other hand from the 'mark'. She drags down a horizontal line and then recounts the eight squares. She then starts to rotate the line. The line is now vertical and connected to the horizontal line but too far to the left. So she starts dragging it towards the right. While she is struggling to drag the line to the correct position she is distracted by something happening in the room [transcript 2] and she turns around to see what it is – leaving the line incorrectly placed. While she is looking away Peter is protesting and comments that the line is incorrectly placed. He starts to explain to her what two squares are in terms of scale and where the line should really be placed. Paying only partial attention to him, she returns to continue her activity of placing the line and places it correctly. [Transcript 3] She then tends to Peter's explanation and says she knows that already, and to illustrate that she has done it correctly she does a recount with her fingers. However, unlike for her previous counts, she

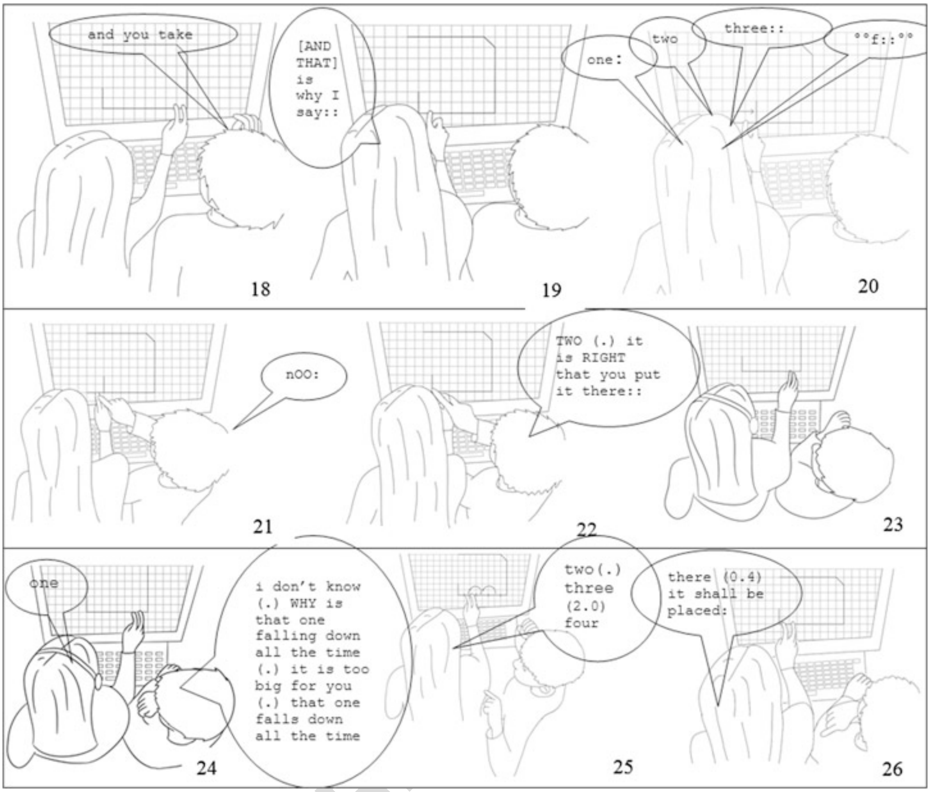


Fig. 5 Transcript part 3

does something wrong and ends her counting-gestures in the wrong square. Consequently, she begins to move the correctly placed line to an incorrect position. Peter now comments that it was already in the correct spot and she moves it back again with him gently pushing her fingers. He starts to comment on a strap over her shoulder "which is falling down all the time". Meanwhile she recounts twice with her fingers, finally confirming the placement of the line.

Nathalie just finished drawing the vertical line on the right side, but before counting along the horizontal line, Nathalie checks her drawing on the paper in the leaflet on the table next to the touchscreen. Coming back into camera view and now sitting in front of the touchscreen she starts tapping and counting along the vertical line (frame 2–6) saying "one (.) two (.) three (.) four". In frame 5, she states "four" and positions her right index finger to mark the end of the four meters. In order to drag down a new line, she swiftly positions her left index finger at the correct position and moves her right hand toward the top area of the screen to drag down a new line (frame 7). As Nathalie drags down the line it slips from her finger and she withdraws her left hand from the horizontal line. As she used her left index finger to mark the end point on the horizontal line there is no sign of where she should position the vertical line. In frame 8 she rotates the line; however, by dragging the right end of the line 90 degrees left and thus position the vertical line two squares further to the left. Having rotated the line, she taps along the horizontal line with a gesture (thumb and index finger) approximating two squares in order to find the right position again (frame 9–11). She marks the right position by swiftly tapping the line and then proceeds to drag the vertical line.

While Nathalie is finding the correct position and rotating the line 90 degrees, Peter is watching her work without directly commenting. As we shall see in the following frames, the problem of positioning the vertical line correctly initiates an interaction sequence where their understandings of scale become visible.

At the outset of this situation, Nathalie attempts to drag the vertical line on the touchscreen, however, the line does not 'stick' to her finger. At the same time and in the same movement she turns her torso and head right, looking away from the touchscreen and out into the classroom (attending possibly to the teacher saying out loud "so I believe it is correctly measured (.) it is THREE METERS in that direction"). When doing so, Nathalie retracts her right hand from the touchscreen and consequently does not finish her placement of the vertical line on the touchscreen and it therefore remains in the same place. The temporary misplacement serves as the basis for Peter's evaluation of Nathalie's work (frame 15–16). Nathalie returns to her original body position oriented towards the touchscreen (frame 14–16), and while Peter is evaluating her misplacement she stretches forth her right arm and begins to move the vertical line towards the correct position. Simultaneously, Peter stretches out his right arm and says "noo:: (0.7) it is a meter (0.2) that is actually like this::" (frame 15–16) and shows his understanding of one meter with a gesture by positioning his thumb and index finger as a way of indicating approximately one meter (two squares on the touchscreen). At first Peter was actually gesturing in front of the touchscreen close to the grid (frame 15); however, when Nathalie approaches the touchscreen again Peter smoothly moves his hand away from the screen to the right (frame 16). Peter holds his gesture next to the touchscreen while Nathalie is correcting her misplacement. However, when Peter is saying "that is actually like this::" and holding his gesture for 1.5 s, Nathalie looks briefly in the direction of his hand, but keeps moving the line to the right. In frame (17) Peter keeps explaining his understanding of a meter, now shifting his gesture to pointing sequentially at two adjacent squares while saying "one meter (.) it is two of those there". All along Natalie is agreeing through verbal feedback (yearh:: right::, mmm, yes) while simultaneously moving the line, which is in the correct position as Peter says "it (0.2) it is two" (however, she keeps adjusting and fiddling with it until frame (17), but it is correctly placed then). As a response to Peter's final comment "it is two of those there" (frame 17), Nathalie agrees again with a "yes". The fact that Peter keeps explaining his analysis of Nathalie's misplacement indicates that he hasn't seen Nathalie's correction and instead he repeatedly shows his understanding of one meter with his gestures. However, in Fig. 5 Natalie takes over the turn by raising her voice saying "[AND THAT] is why I say::" and she starts counting the length of the horizontal line using her index and middle finger (frame 18–20).

From the transcript (frame 20), it is visible that Nathalie hesitates between her count of three and four, and her fingers end up six squares into the line, rather than eight. It is difficult to see from the video, but it seems that Nathalie recalibrates the space between her index and middle finger as she moves and counts along the horizontal line. So while she is demonstrating her understanding and rationale to herself and Peter, she does a gestural miscount and then incorrectly assumes something is not in order. Therefore she decides to move the vertical line from the correct position to an incorrect position two squares to the right (frame 20). In this situation Nathalie does not retract her hand from the touchscreen almost awaiting Peter's assessment of her work. The actual length of the line is now three meters (six squares) instead of four. Having moved the vertical line two squares to the right makes Peter evaluate Nathalie's work once again (Fig. 5). Peter says "nOO: (1.2) TWO (.) it is RIGHT that you put it there::" and then he moves his right hand close to Nathalie's (frame 21–22). Now Peter is gently shepherding (Cekaite 2010) Nathalie's hand from the sixth square to the eight square. Compared to Peter's first evaluation, where he showed Nathalie his understanding of one meter with a gesture close to the grid and next to the touchscreen (frame 15–16), he now moves his right hand close to Nathalie's hand and shepherd her hand to the correct position through touch and movement. However, Peter only shows Nathalie the right place of the vertical line through his shepherding movement and while he retracts his hand Nathalie moves her hand to the right and touches the vertical line and then moves it to the correct place.

After Nathalie places the vertical line in the correct place, the children start orienting themselves to two different things (frame 24–26); Peter starts paying attention to Nathalie's clothes as her blouse strap is falling down from her shoulder whereas Nathalie maintains her focus on the placement of the vertical line. While Peter is commenting on Nathalie's clothes by saying "i don't know (.) WHY is that one falling down all the time (.) it is too big for you (.) that one falls down all the time" just after he glances at her body, Nathalie starts to recount the length of the horizontal line by tapping along it with her gesture (index and middle finger). Nathalie is also counting by nodding her head, moving her lips and pointing to the squares on the touchscreen. In this situation, she is gesturing for herself, and trying to confirm that she placed the vertical line in the correct position, while Peter is oriented towards her blouse strap. She restarts her counting twice, possibly because she is being distracted by Peter commenting on the strap. The activity ends after Nathalie has attempted to count the line three times and finally reaches the end of the line saying and reconfirming "there (0.4) it shall be placed".

Having now explained what is happening in the excerpt and pointed out the subtler details of the children's embodied interaction; we will now analyse, interpret, and discuss the broader implications for CSCL.

Discussion

It should be clear from the preceding section that gestures, touch, body-positions, and body-movements, or what we term bodily-material resources, play a central role in coordinating the children's interaction and collaboration (as does language, of course). It seems that there is a close-knit relationship between the bodily-material resources and language in these situations. There are no signs of language being more important for their coordination and collaboration than the bodily-material resources, and much of the interaction would not be intelligible if we looked only at the spoken language. This, however, is often the case in human interaction around artefacts (Goodwin 2013; Koschmann and LeBaron 2002; Streeck 1996), but as we shall argue the role of the bodily-material extends beyond interaction and communication. In the following we therefore "zoom out" slightly and offer a more analytic and interpretative perspective on their interaction and the relations between collaboration, learning and bodily-material resources. As mentioned initially, we see three distinct ways of using bodily-material resources: 1) as a communicative and illustrative resource for showing each other their understandings, 2) as a cognitive auxiliary tool scaffolding knowledge building, and 3) as a way of shepherding (Cekaite 2010) and instructing each other.

Bodily-material resources for communication and illustration

Throughout the activity, Nathalie and Peter move their hands and body to communicate and illustrate their understandings of scale and one meter, as well as to coordinate their work. For example, Peter produces a gesture with his thumb and index finger (frame 15–16) to communicate his understanding of one meter to Nathalie – and seemingly not aware she is correcting her misplacement or unsure of her reception of his intentions he also points to the screen while saying 'two of those there' to emphasise that one meter is equal to two squares. Peter seems to be working from the assumption that Natalie has not understood the scale correctly, and therefore offers two different gestural illustrations with his hand to explain the correct scale. While he does support these gestures with speech, the spoken language in itself is incomplete, and he never says for example 'it is two squares', but instead 'two of those there' offering the two distinct gestures as resources for Natalie to re-adjust her understanding of the correct scale. Natalie, however, follows up to explain she has not misunderstood and immediately after saying "yes, and that is why I say, one, two, three" she starts to illustrate how she has come to the same conclusion by re-iterating her two-finger tapping gesture (frame 20). These exchanges serve two purposes – one, to coordinate their interaction, but equally to negotiate the correct understanding of scale in relation to the particular material conditions of scale that are built into the information space (paper, screen, squares etc.). Much of this coordination, however, clearly happens with speech as a backdrop rather than as the primary vehicle for meaning-making. The children are positioning each other in the three-termed relationship called scale by co-operating, forming and producing multimodal utterances. Thus, their understanding of scale is anchored in the locally produced bodily-material resources, e.g. it is not a verbal scientific concept for the children yet.

Another, and much subtler, resource for coordinating their work is how they mobilise or conduct their bodies as part of their coordination and collaborative activities. In this particular example their movements are in sync and they follow each other like dance partners. This is very difficult to convey in the transcripts, but in frame 15–16 where Nathalie returns to the screen her arm comes in over Peter's head and he, with an elegant sway, moves his hand to allow her room. Likewise, though they are seated quite close, they don't bump into each other or seem to be fighting over the space. Rather they leave room for each other (particularly Peter). This, however, when looking more broadly at the collected data material is not always the case (Davidsen 2014). In fact, Peter appears in another analysis (Davidsen and Georgsen 2010) at an earlier period in the project. In that situation he collaborates with another girl, where they physically push each other's hands and bodies away to gain screen-control (and he is called to order by the teacher). Thus, and perhaps particularly for children collaborating around shared artefacts, coordination and collaboration concerns not only the verbal interaction and 'turn-taking', but equally bodily-material cacophonic or harmonic 'dances' between the participants. Such 'dances' between participants, or what we could term 'bodily turn-taking' might be interesting indicators of collaboration around touchscreens or other tactile and kinaesthetical interaction spaces. Communicating such synchronous and simultaneous embodied interaction has, however, proved to be a serious problem for researchers (Flood et al. 2015; Sheets-Johnstone, 2012). While our snapshots provide a glimpse of this, there is still room for improvement in making such 'dances' visible for scrutinizing. In fact, it might be worth mentioning that the (very critical-constructive) reviewers of the present article, pointed out that it was quite difficult to follow the spatio-temporal unfolding of events in the first transcript we provided.

Bodily-material resources for cognition

While the use of bodily-material resources for communication and illustration is prevalent throughout the activity, the children's gestures, we argue, also serve other means; namely as cognitive auxiliary tools (Vygotsky 1978) supporting their unfolding understanding of scale and the length of the horizontal line. Peter's gesture using thumb and index finger to approximate what 'a meter is' on the screen can be seen as such a cognitive auxiliary tool. Using the thumb and index finger to roughly indicate a measure seems a more broadly adopted, cultural gesture.[2] However, in this situation it is also used as a more 'precise' measurement, as Peter is attempting to move his gesture closely to the screen – possibly to show more precisely what is the length of 'one meter' – however, Natalie's arm comes flying in and Peter sways away and reproduces the gesture next to the screen, but it is roughly the size of two squares.

Gestures, as cognitive auxiliary tools, are however most prominently displayed by Nathalie's two-finger counting system where she first uses her thumb and index finger and then her index and middle finger to count. We interpret in particular the latter as both a spatial, as well as numerical tool – spatially her two fingers occupy (if held correctly) the same space as two squares, and simultaneously the 'two' fingers can serve as a numerical reminder that it is 'two squares' that equals one meter (on the day before she does count four squares and assume that to be four meters, but is corrected by Peter). In this sense it can be interpreted as a specialised or custom-made tool that orients to or is conditioned by the particular action and information space provided by the teacher. Hence, Nathalie and Peter are using their hands in mobilizing and producing new (though ephemeral) semiotic resources (Goodwin 2000) through their distinct ways of gesturing (or perhaps re-iterating or repurposing gestures that have been employed in similar situations). In addition, the children's hand and body movements are not only "the first materiality by means of which the materials of the situation acquire structure" (Jornet and Roth 2015, p. 397), these bodily-material resources are continuously and dynamically (re)appropriated to the locally produced history of the event, information-, and action-space.

As can be seen from the above interactions, these tools are both 'personal' (they use different gestures), but also 'public' i.e. communicative/illustrative. In fact, in the instance where Nathalie starts counting and makes an error causing her to misplace the vertical line (although she initially placed it correctly) could be interpreted as an in-action transformation from public, illustrative tools towards personal, cognitive tools. She initiates the turn by saying "yes, and that is why I say" and starts visualising and demonstrating to Peter her line of reasoning, and how she arrived at the placement. It, however, results in an error, as she seems to be illustrating more than really 'counting' i.e. it seems a more outward-oriented action. In contrast when she, shortly after, returns to re-count, it is done as what seems a more 'inward-oriented' activity. She is nodding her head simultaneously with tapping and moving her lips with no sound and as, Kirsh (2013) suggests the action of pointing and nodding when counting supports the activity as it heightens the level of attention by the individual. She further re-starts the counting twice as perhaps disturbed by Peter's attention shift towards her blouse strap. In addition, as seen in frames 6–9, Nathalie is swapping fingers in order to keep track of the correct position she just located by tapping and counting along the horizontal line. Thus she is using her fingers as a cognitive tool marking the correct position of the vertical line. This is even more evident when she removes her left index finger from the correct position and starts tapping and counting along the line once again.

Despite the minor errors and breakdowns, their various gestures also demonstrate that they seem to have understood the notion of scale, and that 'something else' can represent one meter

[2] While we often assume some gestures to be 'universal', they might not be. In fact, after a dinner at the CSCL 2005 conference in Tai-Pei a person made eye-contact with the waiter, made a scribbling gesture in the palm of his hand, and was a bit perplexed when he was – very politely – brought a piece of paper and a pen.

in their actual rooms: More so that these relations can be expressed in a number of ways: squares on paper, squares on a screen, as an approximated gesture (Peter's thumb and index finger), tapping two squares, or Natalie's middle-index finger 'counting device'. In fact, in the short clip, there are a number of different 'meters' present in different modalities that they seem to shift more or less seamlessly between. These gestures are of course closely coupled to the structure of the environment, the situation, and the specific technology. However, the environmentally coupled gestures (Goodwin 2007) are mixed and reused depending on the purpose of the gesture, e.g. communicative and/or cognitive.

Bodily-material resources for shepherding

Whereas we see a couple of situations where the children use bodily-material resources for communicative/illustrative purposes and as cognitive auxiliary tools, we only see one situation where their bodily-material resources are used as a way of shepherding or instructing the other. In frame 21–22, Peter is saying 'nOO: (1.2) TWO (.) it is RIGHT that you put it there::' and moving his right hand towards Nathalie's right hand and together they move their hands two squares left, right above the correct position of the vertical line. This particular moment, shows how movement, touch, hands and language mutually constitute each other in a multimodal utterance, and particularly how hands and touch can be used as a resource for shepherding and instructing the other. Nathalie, then, swiftly moves her hand away from Peters and moves the vertical line to the correct place. He is showing her the right place with a gentle shepherding movement, while she is moving herself and the vertical line to that place afterwards. In a way this movement seems to extend our discussion of their bodily conduct. There are different ways of bodily intervening with each other's space (and limbs), and this might also form part of what a fruitful collaboration is or can be.

Embodied interaction in the zone in-between

Having presented, analysed, and discussed the children's use of body-material resources for communication, collaboration, and learning; we would furthermore emphasize that the space in-between children and the touchscreen serve as an important space for these processes to unfold (Fig. 6). Q8

Thus, we suggest that what happens in-between the children and the touchscreen is of crucial importance when trying to understand children's collaborative activities in such a setting. While, it is obviously useful to look at the direct interaction with the screens (number of touches on the screen), we would argue that there are two other types of interaction that are of interest if we want to gain a better understanding of how collaborative learning around touchscreens unfolds. First, we have pointed out that much of their coordination, communication, and collaboration is sustained by movements, touches, and gestures not directly interacting with the screen, but rather are performed in the open space in-between. This in-between space is both the space between the screens and the children, but equally the space between the children. Secondly, we would point to what we could call in-direct interaction or simulation of touch. These are points in time where they are not actually touching the screens, but 'hovering' in front of the screen (as Natalie is counting or Peter measuring or tapping/pointing to squares). Thus, if we rely mainly on analysing the moments where they physically touch the screens (as this is recorded by software) we should be conscious of what we might be missing. We therefore suggest that including the zone in-between can provide a more holistic

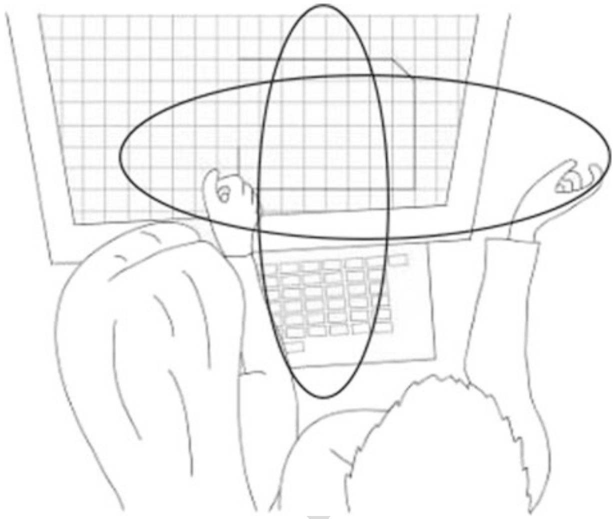


Fig. 6 The zone in-between

understanding of communication, collaboration and learning around touchscreens, as also explored by Sakr et al. (2014).

Wider implications of the study

Our study confirms the need to pay closer attention to the bodily-material interaction, not only as a supplement to speech, but as an important means for collaboration and learning in its own right. Meaning is not only created across the utterances of different people, meaning is created through bodily-material resources among the participants. This, as we have outlined in the sections on "The bodily-material turn in learning and collaboration", is an emerging agenda in other areas of research, as well as within CSCL (Lindwall et al. 2015). While incorporating bodily-material resources, such as gesture, postures, gaze in analysis of interaction and collaboration is not novel in-and-off itself (e.g., Koschmann and LeBaron 2002), we are suggesting a stronger focal attention to these modalities, as they may in some cases be the primary vehicles for interaction and collaboration amongst learners. Thus, these modalities can serve as the initial entrance point into understanding how particular learning tasks unfold, rather than working from an implicit assumption that speech is the prime carrier of meaning in an activity. Furthermore, our example shows that these modalities are quite complex and versatile. In the situation analysed we can see how communicating the notion of scale is accomplished by a multiplicity of gestures meaning 'one meter'. Further, that these gestures are produced as situated, local responses to the information- and action-space designed by the teacher – a space spanning paper, touchscreen, their own drawings, and their 'real' rooms. Thus gestures – or bodily-material resources more generally – are of a more complex nature than seeing them as e.g. deictic, beat and so forth, as we highlighted earlier (e.g. Goodwin 2007; Koschmann and LeBaron 2002). Additionally, we can also see how such gestures may switch between being illustrative/communicative and cognitive auxiliary tools for more inward oriented activities. This also means that registering, coding or automatically recording such gestures can be difficult or turn out to require more analytic attention to the detail of the actual interaction, e.g. how would a system for capturing multimodal learning capture and interpret the shepherding gesture identified in our analysis? As we have highlighted in the sections on coding and counting, automatically recording touches can perhaps overlook finer-grained differences in the meaning of a touch or a gesture; e.g. when are Nathalie's taps communicative, and when are they cognitive auxiliary tools? Furthermore, as we have explored in the previous section quite a lot of communicative work is taking place in front of the touchscreen, as hovering gestures, or in-between the children. As such our study, as well as many others, highlight that the devil is in the detail, and that these details are at risk of being glossed over when applying more overarching analytic categories (such as a touch, pointing or tapping).

Another point we can draw from our example, and from the wider data collection is the notion of development over time. As argued in section on related work on touchscreens, many studies of children's interactions with touchscreens are captured as part of shorter-term interventions and often in experimental settings. However, to be able to say more about learning, than collaboration, one might need to look at data in a more longitudinal perspective. For example, it could be interesting to trace the genesis and development of Natalie's two-finger gesture. How does this gesture emerge, do others adopt a similar practice or is she adopting it from someone else (e.g. the teacher?). Also, as we pointed out in the analysis, we have data examples where Peter is working with another girl, and they are fighting over the shared spaces – bumping into each other, finger-fighting etc. Looking at the data in a longitudinal perspective would open up to questions such as: How does their bodily conduct develop over time, can we trace changes in the way they occupy or intervene in each other's space, and what would this tell us about developing collaboration 'skills'. Thus, a deep and detailed focus on such short-lived moments of interaction can help us understand otherwise unnoticed subtleties of collaboration and learning, while a coupling with a more longitudinal perspective can help us trace the development or the longer-term influences on learning.

In relation to this we should also reflect on some limitations of our own approach. We have mentioned that an inherent danger of experimental 'coding and counting' approaches can be that the broad categories of interaction might overlook more versatile meanings of a particular gesture. While our own approach can identify or uncover such details, it is also clear that it represents a very laborious, time-consuming level of analysis, where we have dug deep into approximately one minute of interaction. We would be very interested in tracing, e.g. the development of Natalie's two-finger gesture. In principle this could be realistic if we remain within the 5 × 45 min of this particular task. However, if we would like to pursue a question such as: How does Peter's bodily interactions with shifting co-learners change over the course of a school year? Is there an overall change in his bodily collaboration or is this more dependent on whom he is collaborating with? Clearly these questions would require us to take an approach with more automated capturing of interaction, such as that explored in Blikstein and Worsley's (2016) review of Multimodal Learning Analytics. While we agree that automated capture of multimodal interaction sounds appealing, it could also suffer from some of the same limitations as we highlighted with similar types of studies in this paper. Perhaps a fruitful agenda would be to develop stronger ties between the research approaches within embodied interaction studies and those working with automated coding, counting and capturing of interaction.

Conclusion

Our main purpose in this paper has been to illustrate that bodily-material resources are important in relation to understanding computer supported collaborative learning, and particularly, of course, the notions of collaboration and learning. By presenting the situation with Nathalie and Peter, we have provided a glimpse of their ways of engaging in collaboration around touchscreens through language and body-material resources. The children's language, gesturing, and movement serve as resources for their individual and shared emergent and developing understanding of 'scale' and the length of one meter, e.g. they are using their hands to produce situated understandings (Koschmann and LeBaron 2002) and as a means of building knowledge together (Stahl 2006). As we have shown, a heightened analytic sensitivity towards bodily-material resources can uncover some perhaps otherwise unnoticed and subtle details of collaborative learning. As Kirsh (2013) suggests, we need to move beyond the cognitive understanding of embodiment and start focusing on 'physical thinking' "…humans use their bodies not just to act on the world and enact or co-create a personal world, they use them to represent, model, and ultimately self-teach." (Kirsh 2013, p. 27). While Kirsh's concept of 'marking' as a way of learning has influenced our discussion of the analytical findings, we also argue that our study adds to this. Kirsh's understanding of embodiment is primarily developed from the perspective of the individual, whereas as our study shows how the children are physically thinking together around touchscreens. Thus, how bodies are used for learning together is still an area to be explored in more depth, and future studies could analyse how bodily-material resources function as ways of thinking psychically together.

In addition, we have illustrated the complexity of how bodily-material resources are used for communication and collaboration, and how the children use the spaces in-between. Such findings that reveal more complex layers of meaning in a gesture or touch on the one hand challenge studies relying mainly on a coding and counting approach, or on automated capture of e.g. gestures. On the other hand, they also suggest fruitful avenues for research collaboration between different approaches that could improve our common knowledge on learning and collaboration. Particularly, this would be relevant for looking at 'development over time', as we suggested in the previous section.

While we have provided insights into the role of bodily-material resources in collaborative activities around touchscreens, we have also experienced some difficulties making the dynamic and simultaneous gesturing and movement visible and understandable to the reader as well as the analysts. Hence, there seems to be a potential for CSCL researchers to better understand and represent the dynamic simultaneous unfolding of embodied interaction to advance theory and method of the field. In this vein, our transcription layout should be seen as a small contribution to a catalogue of ways of making visible bodily-material resources in CSCL settings.

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