

Kindergarten teachers' orchestration of mathematical activities afforded by technology: agency and mediation

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Abstract This paper focuses on kindergarten teachers' interactions with young children during mathematical learning activities involving the use of digital tools. We aim to characterise the teachers' roles and actions in these activities and extend considerations of teachers' orchestrations current in the research literature with regard to agency and mediation. Our analysis of teacher-children-digital tool interaction reveals that the kindergarten teachers took three roles in their work with young children, which we call Assistant, Mediator and Teacher roles. These roles were used interchangeably and purposefully by the kindergarten teachers. With regard to agency and mediation, we argue that agency is distributed over the human and non-human agents in the activity and that agency and mediation are interrelated.

Keywords Affordances · Agency · Digital tools · Kindergarten · Mediation · Orchestration · Teachers

1 Introduction

This paper has two foci: on kindergarten teachers' (KT) interactions with young children in mathematical learning activities in which digital tools are prominent; a critical consideration of extant studies on teachers' interactions with learners in digital environments, with particular regard to agency and mediation. We call the forms of teachers' interactions with children 'roles', which we consider to be interactions made at certain moments in time (roles may, and do, change over the course of a lesson).

The first focus arose from a Norwegian project, *ICT Supported Learning of Mathematics in Kindergarten*, in which we collaborated with KTs to gain insights into young children's

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mathematical learning processes when interacting with digital tools. Several studies have focused on teachers' different roles in technology-using mathematics classrooms at school level (see Zbiek & Hollebrands, (2008) for a systematic overview of such studies). But this paper focuses specifically on the KT and addresses the question: What characterises project KTs' roles when using digital tools in specific mathematical learning activities?

The second focus emerged after data analysis and interpretation of the data in the light of the literature; we 'saw' agency and mediation in the interactions that did not fully resonate with research reports of school level interactions in mathematical learning activities with digital tools. This paper thus also addresses the question: how are KTs' roles related to earlier research on teachers' interactions?

The paper is structured as follows. The next section considers (Norwegian) kindergarten mathematics. This is followed by the theoretical framework which introduces a number of constructs which are used in later sections. We then outline recent literature on the use of digital technology in mathematics education. The next two sections focus on the project: the methodology and selected results. The paper closes with a discussion focused on teachers' roles, agency and mediation.

2 Kindergarten mathematics

'Kindergarten' refers to pre-school institutional care and education of young children. All countries have a form of kindergarten for at least some children and instruction is often mixed with rest and play. In Norway there are public and private kindergartens with trained staff for children from 10 months to 6 years of age. The Norwegian kindergarten is situated within a social pedagogy tradition, i.e., an educational institution where core enterprises are upbringing, care, play and learning.

KTs are trained to attend to the developmental needs of the children, and young children's physical and emotional development is at least as important as their mathematical development. Given their children's relative inexperience in institutional learning the teachers' pedagogic foci, including learning goals, often have to be revised and adapted sensitively. Erfjord, Hundeland, and Carlsen (2012) argue that the teachers' interactions in kindergarten are different from the school context because learning activities in kindergarten and in the school setting are structured differently. In school mathematics, mathematics is the main focus of the teaching whilst in kindergarten mathematics might be included in what is referred to as 'pedagogical activities'.

Mathematics learning in early childhood has increased significantly as a research field (Clements & Sarama, 2007a). In their thorough overview of research in this field, Clements and Sarama go through studies within five areas, (1) number and quantitative thinking; (2) geometry and spatial thinking; (3) geometric measurement; (4) patterns and algebraic thinking; and (5) data analysis. In our study we analyse data which mathematically concerns number and quantitative thinking: the clock, numbers and addition.

3 Theoretical framework

Our theoretical framework is sociocultural in as much as we view teaching and learning mathematics as artefact, person and sign mediated, object-oriented activity. The object

(purpose¹) of the activity for the teacher and the objects for the learners are almost certainly different at the onset of a teaching sequence. In this study we focus on the teacher but we assume that teacher actions are intended to lead the learners to new knowledge. Our expansion of the above uses a number of constructs which we explain in this section: artefact, person and sign mediation; affordances and agency; and orchestration.

3.1 Artefacts, tools, signs and mediation

We consider an artefact as a material object (a thing) that becomes a tool when it is used by a person to do something. The mode of use of an artefact and the intention of the person in this use are important, to realise the intention the person will have a pre-formed idea of the use of the artefact as a tool. We regard these distinctions as important to avoid viewing teacher use of digital artefacts as unproblematic; different teachers may use identical software in different ways and for different purposes. But there are other ways to view artefacts to highlight differential teacher use of software. Behind the 'Trouche form of orchestration' considered below, for example, is a distinction between an artefact and an 'instrument' (see Guin & Trouche, (1999) where the latter is a composite entity—artefact and knowledge (knowledge of the artefact and knowledge of the task constructed in using this artefact)). Although these two views of artefacts generate distinct ontologies around artefacts, their use in highlighting the *problematique* in teachers' use of digital artefacts are similar; both views also acknowledge a dialectic between artefact and person in object-oriented activity over time/use.

Mediation concerns the use of artefacts, people or signs to accomplish goals, e.g., using a calculator to perform a calculation. Mediation is a central construct in any sociocultural framework but the focus on mediational means and the interpretation of the mediator can and do vary over sociocultural researchers. Vygotsky noted that "the basic analogy between sign and tool rests on their mediating function" (1978, p. 54) and distinguished between tool and sign, "The tool's function ... is *externally* oriented; it must lead to a change in objects ... The sign ... changes nothing in the object of a psychological operation ... the sign is *internally* oriented" (p. 55). Mediation takes many forms in institutional mathematics: people (teachers) mediate other people's (children's) activity; the structure of artefacts (from desks to digital technology) in a classroom also mediates student activity. In mathematics classrooms (and elsewhere) forms of mediation act 'in concert': teachers use artefacts and signs in idiosyncratic ways to lead their students to new knowledge.

Within the 'Vygotskian camp' there are ways other than ours to view mediation. Maracci and Mariotti (2013, p. 197), for example, write:

the *mediator* is not the artefact but it is the person who intentionally takes the initiative and the responsibility for the use of the artefact to mediate a specific content. Hence in a teaching-learning context *the mediator is the teacher*, who introduces the artefact to mediate students' appropriation of mathematical knowledge.

¹ We insert "purpose" here and "thing" below simply to distinguish distinct meanings of the same word.

3.2 Affordances and agency

‘Affordances’ is a widely used term in mathematics education. Gibson (1979, p. 127) describes them simply:

The *affordances* of the environment are what it *offers* the animal ... It implies the complementarity of the animal and the environment. ... If a terrestrial surface is nearly horizontal ... nearly flat ... and sufficiently extended (relative to the size of the animal) and if its substance is rigid (relative to the weight of the animal), then the surface *affords support*.

Affordances are appropriate to describe user actions in digital environments: four function calculators afford arithmetic calculations; interactive whiteboards afford a common visual focus amongst a group of sighted people.

Agency is, historically, concerned with an individual’s *free will* (or lack of it). We are rarely, if ever, free to do whatever we please, our actions are constrained by various forces: obvious—syntax requirements of software; and not so obvious—the social conventions into which we are born. Studies of agency examine how artefacts and people shape our actions/decisions. Agency is a central construct in actor-network-theory (e.g., Latour, 2005) and is important in educational studies that consider teachers’ and students’ actions: these actions are rarely, if ever, free actions, they are channelled by culture, other people and the material world (including artefacts). Our view of agency is very close to that of Pickering (1995, p. 6):

The world ... is continually doing things, things that bear upon us not as observation statements upon disembodied intellects but as forces upon material beings ... Much of everyday life ... has this character of coping with material agency, agency that comes at us from outside the human realm and that cannot be reduced to anything within that realm.

To human and material agency Pickering adds disciplinary agency, “It is, I shall say, the agency of a discipline—elementary algebra, for example—that leads us through a series of manipulations within an established conceptual system.” (Pickering, 1995, p. 115). For example, the agency of mathematics leads us to write $a+a=2a$. Pickering coins the term ‘dance of agency’ in performance where agencies “emerge in the temporality of practice and are definitional of and sustain one another” (p. 21). This metaphorical dance can be seen in mathematics lessons with digital tools: the teacher usually takes the lead at the start of the lesson but, as the lesson proceeds, other agents (students, digital tools and mathematics) may take the lead.

Agency is related, but not identical, to affordances. When we use an artefact, we are free to utilise (or not) the affordances of the artefact we perceive but there are often features of the artefact that can have unintended influence (agency) on practice. For example, we might use the affordances offered by GeoGebra to connect four equal line segments to form a square, but this square might be destroyed by subsequently dragging an object connected to the square (i.e., we wanted a square but GeoGebra ‘foiled’ our efforts).

3.3 Orchestration

The term ‘orchestration’ is a widely used metaphor in academic reports of classroom studies. In mathematics education the term is usually associated with Trouche’s (2004) ‘instrumental orchestration’ though other accounts exist, e.g., “The role of the teacher is to

orchestrate the affordances and constraints in a setting in order to maintain a gap between existing abilities and those needed to achieve the task outcome” (Kennewell, 2001, p. 107). The word ‘instrumental’ in Trouche’s account references his theoretical framework, Rabardel’s instrumentation, the primary constructs of which, ‘artefact’ and ‘instrument’, are described above. Artefact and user are interrelated in this account: the artefact shapes the actions of the user, *instrumentation*; the user shapes the use of the artefact, *instrumentalisation*. The process of turning an artefact into an instrument is called ‘instrumental genesis’. Trouche considers the ‘constraints’ and ‘enablements’ of an artefact. Trouche considers three constraints: internal (linked to hardware); command (e.g., the syntax required for use); organisation (linked to the artefact-user-interface). Trouche (2004, p. 296) introduces:

the term *instrumental orchestration* to point out the necessity ... of *external steering* of students’ instrumental genesis ... An instrumental orchestration is defined by *didactical configurations* (i.e., the layout of the artifacts available in the environment ...) and by exploitation modes of these configurations.

Instrumental orchestrations can act at the level of the artefact or the instrument or the relationship between the user and the instrument(s). Trouche (2004) illustrates modes of using an algebraic calculator via a specific configuration which he calls *Sherpa-student-orchestration*. The configuration in this orchestration includes individual students with calculators linked to a viewscreen and it exploits one student (the Sherpa), displaying his/her calculator work to the class. For some years after this paper appeared instrumental orchestration was associated with Sherpa-student-orchestration.

4 The use of digital technology in mathematics lessons

This section positions our analysis/interpretation of our work with KT’s within the research literature. We begin with a brief review of research on the use of digital technology in classrooms. We then focus in on an extension of Trouche’s instrumental orchestration. We now consider our project with KT’s and start by outlining the methodology.

4.1 The use of digital technology in classrooms

The research literature on the use of digital technology in mathematics education is vast but it was not until about 2000 this literature seriously considered the role of the teacher in the classroom; see Monaghan (2013) for details. Further to this, the number of research studies conducted focusing on the use of digital tools in mathematics sessions for young children is small. Indeed, Joubert (2013) notes that ‘orchestrating learning’ was the central theme in a research conference on digital technology in mathematics education (accounting for 84 of the 113 papers) but only five out of 106 papers focused on the use of technology in school settings, focused on primary schools.

We agree with Plowman and Stephen (2003) that research on the teaching and learning of mathematics with digital tools in the kindergarten context is needed. Research focused on young children’s mathematical learning mediated by the use of digital tools of which we are aware includes: Lieberman, Bates, and So (2009), who argue that digital tools are effective with respect to improving the children’s mathematical skills as well as problem-solving skills;

Clements and Sarama (2007b), who investigated the effects of a technology-enhanced mathematics curriculum for pre-schoolers and found that early mathematical interventions positively contributed to children developing their mathematical knowledge; and Gueudet, Bueno-Ravel, and Poisard (2014), which we consider in the next section. Sarama and Clements (2009) provide a rationale of how to effectively use computer manipulatives in general. They argue that computer manipulatives are useful due to their manipulability (flexibility, modification, easier and faster to use than physical manipulatives, immediate and specific feedback) and meaningfulness (computer representations are seen as meaningful as physical objects, e.g., the clocks in Fig. 1).

Zbiek, Heid, Blume, and Dick's (2007) survey of research describes two different roles that mathematics teachers take when they use technology in their teaching: technical assistant (when the teacher assists students with software or hardware problems) and counselor (when the teacher supports students assists students with mathematical problems). Zbiek and Hollebrands (2008) list nine additional roles teachers might take in technology-based mathematics classrooms. As will be seen later, the roles of technical assistant and counselor share similarities with the KTs' roles identified in our analysis.

4.2 An extension of Trouche's orchestration

Drijvers, Doorman, Boon, Reed, and Gravemeijer (2010), and Drijvers, Tacoma, Besamusca, Doorman, and Boon (2013) extend Trouche's instrumental orchestration framework. This work arose from projects which explored teaching and learning mathematics in technology-rich environments in 8th grade Dutch classrooms; the teachers had limited experience in using digital tools in their classrooms. Tasks were presented in Java applets embedded in an e-learning environment. The research questions were focused on describing the types of instrumental orchestrations the teachers used. Drijvers et al. (2013) isolated nine orchestration types (see Table 1) but notes that this should not be regarded as

Table 1 A summary of orchestration types presented in Drijvers et al. (2013)

Orchestration type	Description	Individual (I) or whole class (W)
Technical-demo	Demonstration of technology/techniques by the teacher	I & W
Discuss-the-screen	Whole class discussion about the digital output	I & W
Explain-the-screen	Whole class explanation by the teacher, guided by the digital output	W
Guide-and-explain	Similar to <i>Discuss-the-screen</i> but closed/teacher-led discussion	I & W
Link-screen-board	Teacher links the digital output to paper/book work	I & W
Spot-and-show	Interesting student work is used to stimulate classroom discussion	W
Sherpa-at-work	A student presents her/his work and/or carries out actions at the teacher's request	W
Board-instruction	Teacher writes on the board with no link to technology	W
Technical support	Supporting individual students with issues concerned with technology	I

a complete list. Drijvers et al. (2013) also note whether each orchestration type is used with the whole class or with individual students.

We regard this extension of instrumental orchestration as well considered/argued but we have one reservation, which is especially evident in Drijvers et al. (2010), that orchestration types used are, in general, viewed as teachers' choices. This general statement does have exceptions, for example, "Technological and time constraints as well as control issues may influence the choice and exploitation of the orchestrations" (p. 229). We strongly agree with this statement and view these influences as agencies.

A recent paper, Gueudet et al. (2014), has applied the Trouche/Drijvers' framework to kindergarten mathematics with a theoretical focus on interactions between teachers and resources. Gueudet et al. collaborated with a group of KT's in a similar manner to which we worked with our project teachers (described below): the research group advised on software/hardware, the teachers planned and taught their lessons, the research team observed and analysed classroom activities and all participated in discussion of the classroom work. Gueudet et al. (2014) report on two case studies with classes of 5–6 year old children. A virtual abacus, focusing on base-ten numeration, was used with one class and 'passenger train' (freeware designed to facilitate student use of numbers to record the position of passengers, rabbits, on a train) with the other class.

Gueudet et al. (2014) note similarities and differences with Drijvers et al. (2010). Regarding similarities, "For the introduction of a new software, the Technical-demo, Explain-the-screen, and Discuss-the-screen orchestration types introduced by Drijvers (2012) are still present" (Gueudet et al., 2014, p. 230). Regarding differences Gueudet et al. identify two new orchestration types: *autonomous-use*, "As the children who do not have any difficulties are able to work autonomously with the software, the teacher is "discharged" and can devote herself to the children who were most in need" (p. 226); *supported-use*, "For the children most in need the teacher stays nearby and provides help to the children as they work on the software" (p. 226).

We now comment on Gueudet et al. (2014) with regard to the agency of the software. Although this paper states near the outset, "Orchestrations can be considered as the choices made by teachers" (p. 215), in Section 7 of the paper there is a comment on the 'influence of the software':

Our data clearly demonstrate such an influence ... Concerning the presence of the teacher, with children working on the software, we noticed that it clearly depends on the feedback offered ... Another important aspect of the orchestration that depends on the software features, is the presence of recording sheets to complement the work on the computer ... We assume that a change in the software, permitting the record of children's productions, would certainly change the orchestrations, requiring less written records (Gueudet et al., 2014, p. 230).

Gueudet et al.'s (2014) statement may be seen as a recognition of the agency of the software in instrumental orchestration.

5 Methodology

Our experience suggests that the pedagogical use of digital tools in kindergartens is not prevalent (Hundeland, Carlsen, & Erfjord, 2014). In the course of our research we therefore

invited kindergartens that made pedagogical use of digital tools into our study. The first three authors of this paper and the KT negotiated a co-learning agreement (Wagner, 1997) which recognised that the KTs were the experts in organising learning activities and that the researchers would contribute expertise in theorising and analysing learning activities. By way of this agreement both parties contributed ideas with regards to exploring ways of using digital tools in mathematical activities in the kindergarten. In our discussions with KTs we stated our goal of gaining insights into how mathematical learning activities might be organised with digital tools, what learning opportunities might emerge and how the interaction between the children and the KTs unfolds in those settings.

We collaborated with three different kindergartens, *Bee*, *Swan* and *Frog* (pseudonyms). At least two of the three researchers were present when we conducted three observations in each of the kindergartens. Each session, with 4–5 year old children, lasted approximately 30 min. *Bee* had portable computers available for the children to engage with, while *Swan* and *Frog* both had interactive whiteboards (IWB) available for children's use. We supported the kindergartens with available software and web based applications. The KTs were in complete charge of orchestrating the mathematical activities, applying the available software and applications offered. They did not make special arrangements due to our presence. The observations may thus be characterised as authentic.

At *Bee* we videotaped sessions in which two children at a time interacted with the computer in a separate room in collaboration with a KT. At *Swan* and *Frog* a group of children were sitting in front of the IWB while the KTs were located at the front, next to the IWB, leading the sessions. At *Frog* the number of children in each session was about four while at *Swan* the number of children was larger, up to 15. The video camera was located at the back of the room in order to capture both what was uttered by the adults and the children as well as capturing what was going on at the screens.

When all the video-recordings of the sessions were completed the researchers met to share their reflections on their observations (without viewing the video-recordings). The meeting focused at our recollections and reflections upon observations. We agreed that some of the KTs' actions were related to starting and running software, making sure that one child at a time interact with the software, where to touch/click the screen and so on. Other actions were related to supporting the children to make sense of the applications. The KTs read text, helped in interpreting the screen, and guided the children's focus. A third set of actions were related to asking mathematical questions that went beyond the scope of the application. These sets of actions were then posited to signify three KT roles, the *Assistant*, the *Mediator* and the *Teacher* (see below). We then agreed on observable actions associated with each role related to the didactical configuration and the KTs' guidance, questions and comments.

In the next analytical phase, the researchers individually examined whether the KTs' actions in each video could be matched onto one of these three roles. The research team met again and unanimously agreed that no KT could consistently be said to match only *one* of the posited roles.

In the final analytical phase, the data was analysed in terms of 'moves', where a move is the smallest building block of discourse, verbal or nonverbal, in which one participant holds the floor (Wells, 1999). Each teacher move in the data was independently coded by the first three authors according to the three roles. The researchers agreed that the three roles (and only these roles) were present in the sessions of each KT. There was a high level of agreement and disagreements which were resolved to the satisfaction of all, i.e., there was final agreement on the coding of all the teacher moves.

6 Results

We begin by describing the three roles; these descriptions mirror the observable actions that informed our coding. We then present two coded excerpts from the video data; the excerpts illustrate (i) movement between the roles and (ii) a dominant role over a number of moves.

In the *Assistant role* (AST) to the orchestration of mathematical activities the teachers assist the children with relatively minor issues such as starting and running the software. They organise the activity so that one or more children interact with the digital tools at a time, they give instructions and/or point to places to touch the screen or keyboard and to answer software inherent questions and tasks. For example, in one of the sessions the KT made remarks regarding buttons to press to navigate and choose different games to play. This role includes teacher suggestions about what children should do to engage with the ICT application and by asking the children whether they wanted to play another game.

When KTs took the *Mediator role* (MED) they orchestrated the mathematical activity by being more active in interpreting the digital tools the children engaged with. The Mediator role is further characterised by KTs reading text within the applications and supporting the children in interpreting the screen. The KTs helped the children to become aware of crucial elements and aware of parts of the screen, e.g., Egil's utterances "Now you are supposed to press the clock that shows the time four o'clock" (move 9 below) and "Down here we see some strange symbols" (move 1 below). The applications are prominent agents in this role in as much as a digital output prompts a teacher action.

When KTs took the *Teacher role* (TEA) the application engaged with is used as a mediational means in order to attain mathematical learning goals related to the teacher's objective that go beyond the mathematics unveiled in the application. This is further characterised by how the implicit mathematical concepts and ideas are made explicit by the KTs through use of questions and comments.

6.1 Excerpts from two case studies

The data we present comprises video data from two KTs, one from Swan and one from Bee. The KTs used digital tools covering applications with mathematical elements such as counting, comparing sets, measurements, and shapes. The excerpts analysed below are meant to illustrate the three identified roles. All names are pseudonyms.

At *Swan* the KT Egil, ran software named "Salaby", on an interactive white board (IWB) in front of 15 children. In this excerpt the children are confronted with times represented in two different ways, with number symbols (e.g., 04:00/16:00) and the corresponding times visualised as analogue clocks. In this application all the minute hands were fixed at 12. Eight different clocks displayed eight different times (see Fig. 1). The symbolic times were supposed to be dragged and dropped to the corresponding analogue clocks. Egil shifted between all three roles in the excerpt shown below.

1. Egil (MED): Down here we see some strange symbols (Egil points at 04:00 at the bottom of the screen). It says 0400. What is this? Can you tell me what it means?



Klikk på klokka som viser 04:00 eller 16:00.

Fig. 1 Eight clocks displayed in the software used

2. Children: (Several children raise their hands and “clock” is mentioned)
3. Egil (MED): What is this? (Egil moves his hand pointing at the analog clocks visible on the screen.)
4. Children: Clocks. Clocks. Clocks.
5. Egil (TEA): Yes. What can we read out of this? What can we see from clocks?
6. Children: (Inaudible sound from the children)
7. Egil (MED): We can see what time it is. But, what if the time is one o’clock? What if the time is four o’clock? Who (raise your hand) is able to press the correct one of these (points at the clocks shown at the screen)?
8. Children: (Several children raise their hand)
9. Egil (MED): Janet. Janet, can you come here and try? Now you are supposed to press the clock that shows the time four o’clock.
10. Janet: (She presses the clock which shows seven o’clock. The application makes a sound and nothing happens)
11. Egil (AST): Try once more
12. Janet: (She presses the same clock, and the application’s response is similar)
13. Egil (AST): You will try this one. (Egil also presses the clock which shows seven o’clock; nothing happened). Then you have to return to your seat.
14. Egil (MED): Peter, try four o’clock.
15. Peter: (He tries to press the same clock as Janet. After some hesitation, Peter points at the clock symbol that represents four o’clock).
16. Egil (TEA): Yes. How did you see that this was four o’clock?
17. Peter: (He does not say anything)

18. Egil (TEA): The hour hand points at four and the big minute hand points straight up (Egil points at the clock). Very good.

In the initial moves (1, 3) Egil adopts a *Mediator* role and attempts to focus the children's attention on the cultural symbolism of the analogue clocks and the time slot 04:00/16:00 at the bottom of the screen. He asks the children what these symbols mean and several children utter the word "clock" in response. Both Egil and the children are focused on the screen in these moves (the application is a prominent agent) but the children's response is not what Egil wants from them and he adopts a *Teacher* role in move 5. We interpret his question "What can we see from clocks?" as an indication of Egil asserting his will (agency) in making the knowledge objective clear—the one-to-one correspondence between the times symbolised as numbers and as clocks. Furthermore, in move 5 Egil invites the children to reason about the concept of clocks and hence also the concept of time. The *Teacher* role is short lived and in move 7 Egil returns to the *Mediator* role to explain the meaning of the analogue clocks (an instance of Drijvers' *Explain-the-screen*). Egil selects (move 9) one child, Janet, to come to the front. Janet requires technical help and Egil adopts an *Assistant* role (moves 11 and 13). Egil's knowledge objective for Janet is not attained and Egil selects Peter to try four o'clock (move 14) and Egil briefly reverts to the *Mediator* role before returning to the *Teacher* role (moves 16 and 18). The dialogue effectively ends with Egil's (16) question "How did you see that this was four o'clock?". By asking this question Egil promotes a learning goal that goes beyond interaction with the application (the agency of the application is suspended at this point in the activity). He wants Peter to reflect on why he knew that the pressed clock showed the time four o'clock, but Peter does not respond orally to this invitation. The target knowledge has not been publicly objectified, so Egil summarises what Peter did and explains why the clock showed the time it did.

In the excerpt below, from *Bee*, the KT, Unni, and a child, Trine (5 years of age), also interact with the software "Salaby", but they engage with an application where cars are supposed to be parked into different numbered garages (numbered 1, 2, 3, 4, 5 and 6, 7, 8,

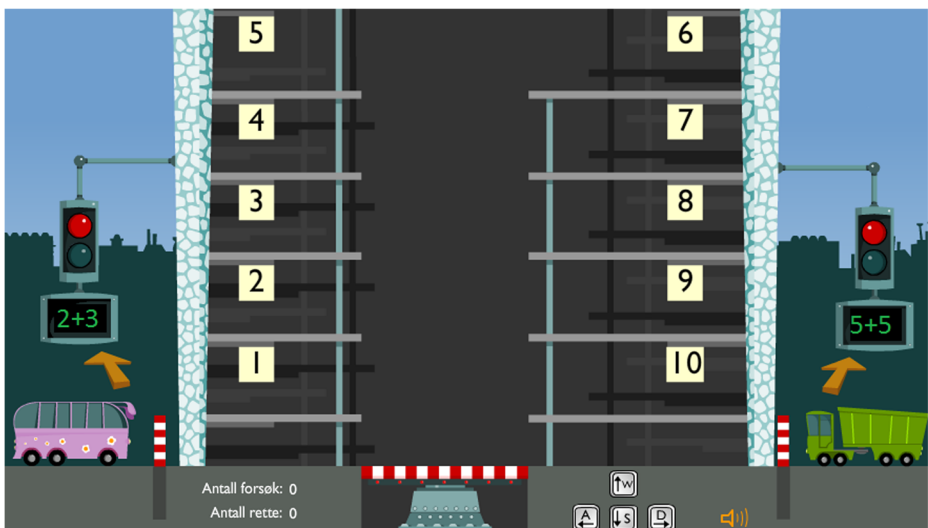


Fig. 2 The numbered garages displayed in the software used

9, 10 on each side of the garage respectively, see Fig. 2). To park a car in the correct garage, the child first has to resolve an addition task such as $2+3$. Then the child needs to correspond the calculated sum with the correct number symbol, 5 (Garage number).

1. Unni (MED): Which car do you want to park?
2. Trine: (Trine points at the lorry on the right hand side where the task is $5+5$)
3. Unni (TEA): Maybe you rather take the other one?
4. Trine: (Trine still points at $5+5$)
5. Unni (MED): You want that one. Which number will that be? $5+5$, how much is that?
6. Trine: (Trine moves the car into the elevator).
7. Unni (MED): Now you have to wait a little bit. Where is it supposed to be parked?
8. Trine: There. (Trine points at the car with her finger, but she appears to be in doubt).
9. Unni (MED): Yes, where will you park the car? How many fingers do I have on my hand (Unni shows her left hand to Trine)?
10. Trine: Five.
11. Unni (MED): Yes, and then you add 5. How many fingers will that be?
12. Trine: Ten.
13. Unni (MED): How does number ten look like?
14. Trine: (Trine points at the correct numbered garage 10).

The dialogue is initiated by Unni (1) who asks Trine what car she wants to park first. Trine (2) makes her choice, the car associated with the addition task $5+5$. Unni (3) suggests that Trine choose another vehicle. Unni is apparently concerned with the difficulty level of the mathematics and wants Trine to start with an easier addition task. However, Trine (4) sticks to her choice of the car labelled with the sum $5+5$. Then Unni (5), following what the application presents, asks two questions with respect to the addition task, both addressing what the sum of $5+5$ is. Trine (6) does not respond to these questions and moves the car into the elevator. Unni (7) then asks Trine to wait and reflect on what she is supposed to do and Trine (8) points at the garage numbered 10; in moves 7 and 8 the screen (the application) is the focus for the question and the answer. As a response to the hesitance shown by Trine, Unni (9, 11) follows up her question from her previous move and addresses the addition problem by translating the problem into a counting problem. She shows the numbers with her fingers ($5+5$) and thus mediates the mathematical meaning of the symbols $5+5$. Trine (10, 12) responds orally with the correct answers “five”—fingers on the left hand, and “ten”—fingers all together. After having figured out the sum, Unni (13) asks Trine to describe the number symbol 10. Trine (14) clearly knows the answer.

In this excerpt Unni predominantly adopts a mediator role in her orchestration of the activity involving one child. The task for the child is to solve the addition problem $5+5$ which the application offers. The mathematical challenge offered by the application is not immediately taken by Trine. Unni thus mediates between the application and the child by transforming the task into a question of counting the number of fingers on her hands. The translation of $5+5$ into a counting task is purposefully done by Unni in order for Trine to realise why the car ought to be parked in the garage numbered 10.

The addition problems offered by the application create opportunities for children to experience addition facts. From the excerpt it is difficult to argue whether Trine realises these addition facts. Like Fuson (1988), however, we consider such addition facts to be possibly advanced mathematics for children. Nevertheless, Fuson argues that repeated

experience with number triplets (e.g., 5, 5, and 10) leads to a cardinal triplet conceptual structure which is important in children's development of number and quantitative thinking.

7 Discussion

Two matters merit further discussion in our opinion: the relationship between the three roles proposed above and teacher orchestrations and roles considered early in our paper; our view of agency and mediation.

7.1 The relationship between this work and work on teacher orchestrations and roles

The three roles (*Assistant*, *Mediator* and *Teacher*) were used by all KT's (although this is not evident in the Bee excerpt) and the roles were mixed (they alternated). Our research findings share similarities with some orchestration types found by both Drijvers et al. (2010, 2013) and Gueudet et al. (2014) but there are also substantial differences.

Of Drijvers et al.'s (2013) nine orchestration types, there were no instances in our observations of: *Discuss-the-screen* (whole class discussion) and thus of *Guide-and-explain*; *Spot-and-show*; *Sherpa-at-work*; or *Board-instruction*. A possible reason for this is the limited techno-mathematical work expected by KT's of kindergarten children. There were, however, instances of KT support of children's work that approximated to *Technical-demo*, *Technical-support*, *Explain-the-screen* and possibly *Link-screen-board* orchestration types. *Technical-demo* is characterised by demonstration of techniques as well as a certain didactical configuration, e.g., access to the application(s) and classroom arrangements. This type of orchestration thus shares similarities with what we have called an *Assistant role*. However, as can be seen in the KT moves marked AST in the excerpts above, the KT's do not demonstrate the possibilities of the applications but, rather, they manage/mediate basic child-computer interaction: "Try once more". Similar comments can be made of our project KT's with regard to *Technical-support*. *Explain-the-screen* also has some shared features with our project KT's *Assistant* and *Mediator* roles. *Explain-the-screen* is characterised by the teacher guiding the students with regards to what happens on the screen and with respect to both technical matters and to the mathematical content. In terms of mediation, *Explain-the-screen* orchestrations may be viewed as those in which the teacher mediates between: the screen and the students; and the technical and mathematical aspects of the tool. The digital tool is a prominent agent in this mediation. These aspects of *Explain-the-screen* have similarities to our *Mediator* and *Assistant* roles but these two roles did not involve the exploitation mode where KT's took "student work as a point of departure for the explanation, or start with their own solution for a task" (Drijvers et al., 2013, p. 999).

In our analyses there were no incidents of the *Link-screen-board* orchestration type, i.e., of teachers trying to link the mathematics implicitly or explicitly present on the screen with written mathematics on a board or on paper. However, if we interpret this orchestration type to a KT's objective of getting the children to make sense of the mathematics, we could argue that it has similarities to our *Teacher* role; but the didactical configurations in *Link-screen-board* and *Teacher* role are quite distinct (no board other than the IWB was used by the KT's).

We now compare our findings with those of Gueudet et al. (2014). They (like us) found *Technical-demo* and *Explain-the-screen* but (unlike us) found *Discuss-the-screen* orchestration types were present in their observations. However, Gueudet et al. (2014) augment the orchestration types with two new ones, *autonomous-use* and *supported-use* which concern supporting individual children in need (orchestration types to support individuals was not considered in Drijvers et al., 2010 but was considered in Drijvers et al., 2013). In our work with kindergartens we did not find it productive to differentiate between individual and whole-class orchestrations as the social division between children who have/do not have difficulties (which prompted Gueudet et al.'s (2014) two new orchestration types) was not apparent in our KT's actions. However, the orchestration type *supported-use* might be argued to share characteristics with what we have called a *Mediator role*. Both the orchestration type *supported-use* and our *Mediator role* are characterised by the teacher helping the children in interacting with the digital tool. Nonetheless, there are differences as well. The *supported-use* orchestration is used to describe situations in which teachers support students that are most in need while working individually with the tool. This situation is very different from ours, since our data are collected from kindergartens where the children are not left alone interacting with the computer. Both the *autonomous-use* and *supported-use* offered by Gueudet et al. (2014) are thus not appropriate for the orchestrations conducted by the KTs in our study.

Our description of the Assistant role shares similarities with what Zbiek et al. (2007) call 'Technical Assistant' and our description of the Mediator role shares similarities with what Zbiek et al. label a teacher's Counselor role. However, our definition of Mediator is a pro-active role while the Counselor role is more passive as teachers adopting this role provide mathematical assistance only when it is asked for by students. None of the additional nine roles identified by Zbiek and Hollebrands (2008) fully covers our Teacher role. Their Facilitator, Evaluator and Explainer roles address parts of our description of the Teacher role, but none of these acknowledge the form of interaction where the mathematics inherent in applications are used to serve a mathematical learning goal beyond the scope of the application. These differences might be due to the fact that Zbiek et al. studied mathematics teachers at school level.

7.2 Agency and mediation

In our excerpts we see agents (teacher, child, digital tool and mathematics) interacting in what Pickering (1995) calls a 'dance of agency', that is, each agent taking turns to 'lead the steps' of the activity. We illustrate this dance in each case study excerpt:

- At *Swan*, Janet comes to the front (moves 10 to 13) but needs help from Egil to act as he wants her to act by using the affordances offered by the application.
- At *Bee*, after Trine sticks to her choice of $5+5$ there is a three agent dance of agency: the application presents the task; Trine makes her choice; Unni attempts to change Trine's choice; and Trine resists Unni's attempt to change her choice. This dance is, we believe, prompted by Unni's desire to mediate the mathematical meaning inherent in the application's task.

Whilst Pickering's 'dance of agency' is a suitable metaphor, we prefer the term 'distributed agency' for the impetuses for action in the excerpts are distributed over the

agents-in-activity. We further consider agency and mediation to be interrelated in adult-child interaction and 'artefactual' agency and mediation are related with the person-environment affordances. As noted above (subsection on agency and affordances), we are free to utilise (or not) the affordances of the artefact that we perceive but features of the artefact can have unintended influence (agency) on practice. This is evident in the *Swan* excerpt, where the software presents the task and the symbolism but later (lines 10 and 12) does not respond as wanted/expected.

We now return to our criticism that orchestration types are *teachers' choices*. Our KTs are making choices in these excerpts but these are situated choices which are interrelated with the affordances of the environment. We think that Drijvers et al. (2010) use the phrase *teachers' choices* in an everyday manner. In day-to-day life we speak of choices when we know they are really bounded and this is implicitly recognised by Drijvers et al. (2010). Our criticism of the use of this phrase is that it obscures the influence/agency of digital tools in understanding teachers' use of digital technology in mathematics classrooms.

With regard to Maracci and Mariotti's claim that "the *mediator* is not the artefact but it is the person ...", we acknowledge that there is a great deal of teacher mediation in these excerpts but there is also artefact mediation; indeed, much of the teacher mediation is centred in 'funneling' the software output. Perhaps Maracci and Mariotti are overstating a point. Prior to this quote they are critical of the mathematics education literature on the use of artefact:

The study of the mediating function of the artefact is often limited to the study of its role in relation to the accomplishment of tasks, while the complexity of the relationship between the student's accomplishment of a task and mathematics learning risks to remain in the shadow.

We agree with this criticism. Indeed, the Vygotskian mediational triangle (subject/tool/object) is often interpreted as subject \rightarrow tool \rightarrow object but, as Cole (1996, p. 119) points out, "the incorporation of tools into the activity creates a new structural relation in which the cultural (mediated) and the natural (unmediated) routes operate synergistically". This synergy, we feel, arises from distributed agency and mediation in activity.

8 Conclusion

As noted above, it was not until about 2000 that research on the use of digital technology in mathematics education seriously considered the role of the teacher in the classroom. Since 2000, however, studies in this area have advanced understanding. A dominant construct in this advance is 'instrumental orchestration', which we consider to have a strong construct validity, but perhaps it is time for mathematics education research to widen its scope and consider digital tools as agents and mediators in classroom activity.

Research on the use of digital technology by teachers in kindergarten mathematical activity is scarce and this paper contributes to this area. We posit and illustrate three 'roles' and note similarities and differences to teachers' orchestrations and roles in extant studies. Our interpretation of these roles pays more explicit attention to the 'distribution of agency' (over teacher, child, digital tool and mathematics) than other studies. We view our work as having the potential to widen scholarly discussion, with particular regard to agency and mediation, in this area. Moreover, further research is needed which investigates children's learning when teachers take on the different roles.

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