Mathematics teachers' initial implementation of a digital tool package

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The study reported in this paper was situated within developmental research and concerns teachers' initial implementation of a digital tool in mathematics teaching. The paper illuminates two types of implementation processes, and takes an activity theory perspective in the discussion of reasons and the types of issues experienced and addressed in the implementation processes. Using activity theory parlance it is argued that although the teachers appeared to have rather similar objects for the implementation, there were great differences in teachers' goals and the kinds of issues dealt with in the implementation processes. The schools' organisation, internal collaboration within each school and how the external requirements for mathematics teaching, such as a curriculum and examination standards, were approached, played a significant role in the different implementation processes.

Policy makers, school authorities and educators have for decades tried to promote implementation of different kinds of non-standard tools, including digital tools, in school teaching. Research has shown many barriers involved when teachers try to implement a tool in teaching for the first time (Berry, Graham, Honey & Headlam, 2007). During the last decades, many studies have considered teachers' implementation of digital tools in *mathematics teaching*. Implementation of digital tools has been argued being particularly demanding because the implementation typically involves both new teaching methods and the integration of computers for the learning and teaching (Barzel, 2007). Students' work with digital tools in mathematics is challenging to manage and control, and *time* is often a key issue preventing use of digital tools. The reason is that the implementation involves both reserving extra

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time for planning and extra time for digital tool use in teaching which additionally is difficult to control (Assude, 2005).

The aim of this study was to pinpoint reasons why some teachers implemented a digital tool package in their mathematics teaching, and to outline issues dealt with in their implementation processes. Two quite different implementation processes are characterised and discussed. The research question guiding this paper is: *What characterises mathematics teachers' initial implementation of a digital tool package*? "Initial" here means that the teachers never before had used the tool in their teaching.

Digital tool implementation

Many studies have considered factors and issues involved in teachers' implementation of digital tools in mathematics teaching in schools (e.g. Crisan, Lerman & Winbourne, 2007; Goos, 2005). I argue that the factors Goos (2005) outlines are comprised of four quite different kinds: i) access to materials (computers and appropriate digital tool packages); ii) teachers' digital tool competence both in using the tool and supporting students' mathematical learning with the tool; iii) support for development of teachers' competence within the school; and, iv) teachers' beliefs about mathematics and mathematics learning. Crisan et al. (2007) distinguish between *contextual* and *personal factors* involved in the implementation process of digital tools in mathematics teaching at secondary school level. Their eight contextual factors are similar to the types above from Goos listed as i) – iii) while their five personal factors are similar to iv).

Research on digital tool implementation more in general, has reported many of the same kinds of factors as highlighted by Goos (2005) and Crisan et al. (2007). In particular, the role of school and technology leadership as well as involvement of many teachers, have been argued as crucial for implementation of digital tools and sustainable developments at schools. (Tondeur, van Kerr, van Braak & Valcke, 2008).

Building on the insights from previous research, this paper explores and compares what kinds of issues teachers dealt with in their initial implementation processes of a digital tool at lower secondary mathematics teaching in Norway. One quite large and one quite small school with teachers were selected for the study. Teachers at both schools were engaged in initial implementation of dynamic mathematics software (DMS).

An activity theory perspective

This paper adopts cultural-historical activity theory, in this paper simplified to the term *activity theory*, in the analysis of teachers' implementation processes. As a socio-cultural theory, activity theory builds on the view that learning and teaching are tool mediated and socially oriented. Activity theory distinguishes the individual and social by accounting for differences between personal actions within collective activity (Leont'ev, 1978, 1981). Kaptelinin (1996) suggests *activity*, *actions* and *operations* as three main levels to focus on when analysing educational practice with an activity theory perspective:

> *Activities* are oriented to motives, that is, the objects that are impelling by themselves. Each motive is an object, material or ideal, that satisfies a need. *Actions* are the processes functionally subordinated to activities; they are directed at specific conscious goals. According to activity theory, the dissociation between objects that motivate human activity and the goals to which this activity is immediately directed is of fundamental significance. Actions are realized through *operations* that are determined by the actual conditions of activity. (Kaptelinin, 1996, p. 108)

In accordance with the outlined distinction by Kaptelinin, teachers' motives for their initial implementation of a new digital tool package are analysed by considering what the teachers wanted to achieve with their actions in the implementation processes. The teachers faced and addressed issues, which according to activity theory were energised by their personal goals with the implementation and eventually when teaching with the new tool. The final level, the operation-level, is not the centre of focus in this study, which would have concerned the detailed accomplished teaching. Previous research has also adopted these three main levels in analysis of mathematics teachers' digital tool use. In Erfjord (2011), teachers' design and use of worksheets with digital tools in mathematics is analysed with the help of Leont'ev's constructs. The teachers in Erfjord's study were experienced users of the digital tool package used, while this paper considers teachers' implementation of a DMS-tool they never had used in their teaching.

This paper adopts another theoretical construct within activity theory, "activity system" (Cole, 1996). An activity system is characterised as stable, where ways of working have developed over time and the role of a shared object is critical. Interpreted in the context of schools, a group of collaborating mathematics teachers at a school may work as an activity system with a quite general shared object of developing and conducting excellent mathematics teaching resulting in good achievements by their students. A more distinct shared object could be implementation of a new digital tool in their mathematics teaching. Engeström (1999) defines a "complex model of an activity system" where the "community" includes all people being directly and indirectly involved in the activity. The "subjects" are the people more actively engaged. In my reported study, the subjects are one or several mathematics teachers working together for the shared "object". Engeström lists four other main constructs: "rules", "division of labour" and "mediating tools". An activity system is governed by some explicitly or implicitly expressed rules, such as use of the same mathematics tests in all classes at a grade, and established division of labour for the involved community. Actions are accomplished by use of mediating tools such as textbooks and particular digital tool packages. Finally, Engeström proposes "outcomes" as the results of the activity system's work, and he links the outcomes to the objects from which they are achieved but related to the whole activity system.

In a school setting, at least three main types of activity systems can be defined (Lim & Hang, 2003). In the classroom, students are the subject of the activity of learning while the teacher is the subject of the activity of teaching but both groups are involved in their respective activity systems as part of the community. I denote these two activity systems as *learning activity system* and *teaching activity system* being at a class level with one or several teachers. A third kind of activity system is at the school level with collaborating teachers and leadership.

For the analysis of data in this paper, school activity systems are the main focus of attention. The initial decision and planning for use of the digital tool, which is what I denote as the implementation process, took part when one teacher or groups of mathematics teachers at a school sat down and planned the use of the tool. School leaders and didacticians[1] were present in a few of the meetings and are consequently considered being part of the community. The teachers' concern was also for the next stage, their teaching with the tool, but primarily on content level and planned way of working. Thus, the teaching activity systems are not a main focus in this paper. However, I argue that teachers' desired outcomes during the implementation process energised their efforts to develop motives into collective objects and indicate their personal goals for the implementation. This becomes evident in the discussion section where analytical findings of *why* (teachers' reasons) and *how* (issues raised and addressed by the teachers) are discussed with references to motives and goals, and actions, respectively.

Methodology and research methods

The study reported in this paper was situated within a project which adopted developmental research methodology (Freudenthal, 1991). The project intended to have impact both on teachers' use of digital tools in mathematics teaching and on didacticians' mathematics education research, and was accomplished by designing cyclical relationship between activities set up for teachers' professional development and the research lead by the didacticians. Freudenthal argues for the beneficial insight this kind of methodology offers: "experiencing the cyclic process of development and research so consciously, and reporting on it so candidly that it justifies itself, and that this experience can be transmitted to others to become like their own experience" (p. 161). Both teachers and didacticians contribute to the development and research with their different expertise on respectively teaching and research.

In this paper the methodology offers insight into the complexity of teachers' implementation of digital tools. The schools and teachers referred to in this paper were part of a three-year project where use of digital tools in mathematics teaching was a key focus of attention. The author of this paper was one of the didacticians from the university. Collaboration with teachers for many years offers insight to the complexity of the work in schools and issues involved in developmental processes. A possible disadvantage with such close collaboration, is that claims being made from research within developmental research is largely situated and considered less generalizable than less impacted research missing the possibility to observe "regular" practice. However, within developmental research there are big possibilities to achieve in-depth insight about the developmental processes and into the different roles played by teachers and didacticians. The very way of working in the development projects also contribute to the trustworthiness in that openness and mutual respect for each others' expertise are possible in developmental projects. Research literature uses the term "co-learning partnership" (Wagner, 1997) to describe such respect and ways of collaboration. Thus I argue for the benefits of the methodology in capturing implementation processes of teaching.

Research participants

Data was collected with teachers at grade 8 from two schools. School 1 is a rather small school with only one class and one mathematics teacher at each grade. The other school, School 2, has four classes at each grade taught by in total three mathematics teachers (two teachers had one class each while the third teacher taught two classes). The classes consisted of approximately 25 students which is a quite normal size for classes in Norway. The rationale for selecting one rather big and one rather small school for this study, was to capture possible differences related to school organisation and the types of factors involved in the implementation processes (cf. Crisan et al., 2007).

The mathematics teacher at School 1 was a female, Anna, while the three mathematics teachers at School 2 were males, Bent, Carl and David. Except for David, they took part in the project workshops, interviews and school meetings and their lessons were observed. However, according to Bent and Carl, David wanted to use the DMS-tool with the same prepared instruction material and tests as them. The principals at the two schools were only present in one school meeting each. In these meetings, use of DMS was mentioned but not discussed in any depth. Some other mathematics teachers, who taught mathematics at grade 9 or 10, participated in project workshops and in school meetings. In these events implementation of digital tools was discussed, but not with emphasis on the detailed choices in content and use of instruction materials which were typical in meetings which only involved the teachers at grade 8. A didactician (the author of this paper) was present in all sessions where the matter implementation of the tool had been reported being at stake, but was not involved when detailed plans for teaching, choice of instructional material and organisation of lessons and tests were outlined.

The DMS-tool

The digital tool at stake was a DMS-tool for mathematics teaching. The teachers implemented the DMS-package Cabri Geometry, which the following year was switched with GeoGebra. DMS-tools are considered being flexible tools with big potential for the teaching and learning of mathematics in schools, and are now widely spread and used (Ruthven, Hennessy & Deaney, 2008). GeoGebra is the most used DMS-package in Norway (Hals, 2010).

Ahead of the developmental project, the teachers had briefly been introduced to DMS in in-service training. In addition, the most recently educated teacher at School 2, Carl, had been introduced to DMS in teacher education. However, none of the teachers at the two schools had ever used DMS in their teaching. During the developmental project, teachers and didacticians spent some of their common time in project workshops and in meeting at the schools on investigating and discussing possibilities with DMS (both Cabri Geometry and GeoGebra) for mathematics teaching. Consequently it is sound to claim that the schools' and teachers' decision to be part of the developmental project, where DMS was introduced possibly influenced their decision to implement DMS in their teaching.

Data material

The study reported in this paper uses data collected in different kinds of project events and observations of classroom activities. Such events include school meetings, informal conversations and one focus group interview in each school where possible use of DMS and issues involved in a possible implementation were discussed. Project workshops with teachers, where DMS-use was discussed and eventually experience from initial implementation and use of DMS were shared. Finally, lessons where DMS was used and meetings afterwards where developed insights and ideas for further use were discussed. In total, empirical materials from more than thirty sessions comprise the study while the data particular for this paper's focus on implementation of DMS comes from eight as illustrated in table 1.

Event 1 occurred almost half a year before Event 2, while the planning meetings (Events 2–5) took part within a month. The project workshops

Table 1. *List of events considered in this section*

Event	Type of sessions	Participants and brief content
1	Project workshop at UiA	All project teachers and didacticians working with DMS-tasks on a computer lab for the first time in the project. Initial presentations by didacticians, discussions and presentations by teachers near the end of the workshop.
2	School 1 team meeting	Anna and two other project mathematics teachers at other grades, the principal and three didacticians were present. Possible ideas for digital tool use discussed.
3	School 2 team meeting	Bent, Carl and two other project mathematics teachers at other grades, the principal and three didacticians were present. Possible ideas for digital tool use discussed, and some previous problems with lack of access to digital tools and bad experience at the school shared.
4	School 1 team meeting	Anna and two other project mathematics teachers at other grades and two didacticians were present. Plans for use of spreadsheets and possible use of DMS discussed.
5	School 2 team meeting	Bent, Carl and two other project mathematics teachers at other grades and three didacticians were present. Bent and Carl announced plans for use of DMS a month later.
6	Project workshop at UiA	Anna at School 1 announced that she the day before had used DMS in teaching for the first time. Carl informed about plans for use of DMS the coming week at School 2
7	Project workshop at UiA	All project teachers and didacticians present. In small group sessions with teachers from different schools, Anna, Bent and Carl shared their experience from initial DMS-use in teaching at School 1 and 2.
8	End of DMS-use interview at School 2	Bent, Carl and two other project mathematics teachers at other grades were present. Experience from their finalised initial teaching with DMS shared as well as students' outcome in tests.

and interview (Events 6–8) took part during and just after the initial teaching sequence with DMS a month after Event 5. Data were collected with the help of audio recordings, video recordings and field notes.

Data analysis

The data analysis was done systematically. First, a creation of a very brief descriptive overview of the content in each collected event was made as indicated in table 1. The aim with this initial stage was to help in using the whole set of data and which parts to analyse in depth. It was decided, based on commonalities and relevance for the research question, which sessions and parts of sessions to include as data for the paper and to transcribe in detail. Schools and teachers were coded with pseudonyms. The aim was to create a comprehensive picture of teachers' implementation processes of DMS and the kinds of issues involved. Data from various sources and periods of time contribute to the validity of the study in what Yin (2003) describes as a "convergence of evidence" (p. 100). The main stage of data analysis was analyses in depth what was raised by teachers in each event. Data was coded in two main phases. In phase 1 data was given descriptive text such as "fear and desire" and "expectation". These codes were revisited and re-coded in a phase 2 after the whole material had been coded. The two mentioned codes were in phase 2 re-coded to "lack of self-confidence" and "external expectation". This analytic process resulted in twelve different codes which were compared again, and two main categories emerged from this process: Category 1 with codes comprising *reasons* for the DMS-use, Category 2 with *issues* involved in the implementation of DMS. Additionally, some pieces of the coded data were also categorised as a chained combination of Categories 1 and 2. These were situations where the desire of overcoming an issue became a reason as illustrated below in the first row in the right column of table 2. In the table, the main stage of the analysis process illustrating coding and categories is exemplified for the part of Event 6 which concerns discussions of Anna's implementation.

Analysis and results

This section reports findings from the analysis of teachers' implementation of the digital DMS-tool at two schools. As reported above, two main categories emerging from the data analysis process highlight *why* (category "reason") and *how* (category "issue") the implementation took place. By giving attention to these two aspects, it becomes evident why teachers implemented the new tool and what they experienced as crucial in their implementation processes.

Table 2. *Illustration of codes and categories*

Brief content	Teacher's comments	Codes, phase 1	Codes, phase 2	Categories
Anna at School 1 announced that she the day before had used DMS in teaching for the first time.	To dare using DMS in teaching despite fear	Fear and desire	Lack of self-confidence	Issue and reason
	Experiencing an expectation to use digital tool such as DMS in teaching	Expectation	External (and internal) expectations	Reason
	A need to reserve extra time	Reserve time	Reserve time for personal development	Issue
	Want to see students' collaborative learning with DMS	Desired students' role	Students' collaborative explorations	Reason

Teachers' reasons for implementation of the new tool

Access to the digital tool package is obviously crucial for implementation of the tool. *School licenses* for the DMS-tool Cabri had been bought at both schools one year in advance of their initial implementation of the tool. This indicates that both schools had a commitment to the developmental project where use of digital tools was a focus of attention.

Anna expressed a *perceived expectation* to implement the DMS-tool as a consequence of the school's participation in the developmental project. This kind of project commitment expectation was not explicitly mentioned by neither Bent or Carl, nor by teachers from other schools. In workshop sessions didacticians had suggested that the software could be a good choice for the learning of mathematics. However, an explicit commitment to implement a particular digital tool had never been stated either written or oral in the project. Nevertheless, the fact that schools in the project had volunteered to participate in a project with a focus on digital tool and in addition bought a school licence for DMS-tool, meant that school leaders and possibly teachers at the schools had ambitions to see the tool being used in teaching. It is also not unlikely that Anna and possibly others saw the initiative from the didactician in workshops, other school's implementation of the tool and the fact that the school had signed in for project participation as an expectation to commitment on implementation of this particular DMS- tool.

Opportunities to get *support* from other teachers and didacticians within the project were also expressed as crucial. Bent and Carl mentioned opportunities for guidance from didacticians and access to material such as worksheets as reasons why they wanted to implement the tool themselves. These three reasons: school license, project commitment and project support had an external character but still the teachers at each school had to do the main effort and desire to use the tool in teaching.

Concerning the more personal reasons why the teachers implemented the tool, clear differences between the two schools were found. The personal reason expressed by Anna was a desire to *dare* to implement the DMS-tool despite her own expressed lack of competence in using digital tools. In a project workshop with teachers from School 1, 2 and other schools, she uttered the following statement indicating this desire:

> I know that I am not clever with digital tools. So it was big efforts and many new considerations. I started to read the worksheets [refers to a number of DMS-worksheets handed out in a project workshop] and, then I thought, dammit, I just have to do it! ... On Friday I decided to do it!.

Anna's statement came five days after her first ever conducted teaching lesson with the new tool. A second reason for her efforts appeared to be an expressed wish to experience *students' investigations* of opportunities with the new tool and to share experiences with each other. In observations of her lessons, this was evident in that she gave few instructions to the students ahead of their work besides offering written tasks without explaining any procedure on how to approach the tasks with the tool. An example is the following written by her on a flip-chart ahead of a lesson: "Construct an equilateral triangle and investigate their properties". Alongside the written task she said: "You are allowed to play and practice and try to make an isosceles and equilateral triangle". Afterwards, when she in a conversation referred to the lesson, she was very happy to see that "they started off and it was such fun to watch them" which indicates that it was such student investigations with the tool she wanted to observe.

The personal reasons for implementation of the DGS-tool expressed by Bent and Carl were different compared to Anna. In several meetings ahead of their initial lesson with the tool, Bent and Carl expressed a desire to *do something new* in mathematics. In a focus group interview with the teachers after their initial use of the tool, Bent phrased it in the following way: "We had a desire to do something new in mathematics teaching. It is constantly said that the state of affairs in mathematics is so bad now compared to before and all the problems that this gives". This utterance also pinpoints that the reason appeared to be shared among the two teachers and David. The latter is also evident from a comment by Carl later in the interview, where he emphasised the collective dimension: "It was not only one who had to do it on his own but we were several who wished to use the new software". The other main reason expressed by Bent and Carl was a hope to *increase students' motivation and performance in geometry* based on a combined use of DMS-tool and the more established use of ruler and compass in geometry lessons. An indication that improved performances was a driving force for the efforts, came in an open presentation held by Bent and Carl one year after their initial implementation and use. There Bent reported with enthusiasm that their grade 8 students had improved their skills in geometry after using the new tool in combination with compass: "During this year on grade 8, students' skills in mathematics have improved. It's great!".

This section has revealed a number of reasons why teachers at two schools wanted to implement a DMS-tool. In the following sections, issues involved in the implementation processes are illuminated.

Time as a key issue in the implementation processes

A main issue considered by all the teachers in the study was *time*. The three kinds of time related factors addressed by the teachers were: i) personal competence development, ii) planning for use of the tool in teaching, and iii) teaching with the new tool. Below examples are provided to illustrate how the teachers with different emphasis addressed these factors.

When Bent and Carl in an interview, some weeks after their initial use of the tool, talked about their implementation of the new tool, they referred to time as an issue. Bent uttered: "We decided to prioritise geometry. We reserved extra time for it". What Bent here referred to, seems to be what Assude (2005) characterises as "the didactical time", the time teachers devote for teaching of the different topics in mathematics and above is labelled iii). Assude found that teachers are well aware that more of the didactical time is needed to reserve for the geometry topic if DMS is supposed to be used. The time-related issue ii) was evident by comments in meetings ahead of the use of the tool when Carl mentioned a prepared instructional material for the DMS-use. The instructional material had been developed by a teacher elsewhere in Norway, and according to Carl made with the intention to be efficient for students' work with DMS at grade 8 avoiding "students spending too much time on the tool use". Thus, this indicates that the teachers saw the use of a prepared instructional material both being time efficient for their own planning and guiding teaching and students' work with the tool. Such a wish corresponds also well with findings reported by Assude. She found that teachers experience it being difficult to govern the didactical time used when working with a new tool like DMS, and refers to ”time saving actions” as something teachers develop based on experience after using a tool initially in teaching. By using a prepared instructional material, the teachers could exploit potential time saving actions made by the teacher who had prepared the instructional material based on experience with DMS use. Thus, I argue that Bent and Carl mainly were concerned with the time issue related to ii) and iii) in the list above. Additionally, in preparing for the use of the instructional material it is reasonable to argue for a parallel time efficient process which concerns point i), their own personal development, despite this not being explicitly expressed by the teachers.

Anna was also concerned for time as an issue for the implementation of the new tool, but, in contrast to Bent and Carl, she explicitly and repeatedly argued that she needed to reserve time for personal development. In a project workshop ahead of her first ever use of the tool in teaching, she gave the following statements: ”I need to reserve time for my own development with the tool. For me it is of necessity, if not I will not manage it.” As quoted in the previous section, she considered herself not being clever with digital tools. An utterance, one week after her first lesson with the tool, indicates that lack of digital competence was a main issue which she had overcome: ”It was such a lesson and it, it went equally well in the lesson afterwards. I really shouted loudly. I was able to do a proper job!” Anna's initial judgement of her own competence with digital tools corresponds with what Russell and Bradley (1997) label ”computer anxiety”, where teachers express embarrassment about own inappropriate use of computers. Thus, the dominating issues for Anna was her own lack of digital competences (above labelled i)) and planning for use of the tool (ii). Anna seemed little concerned with (iii), the extra time used for teaching with the tool, which was a main concern for Bent and Carl.

Other issues considered in the implementation processes

All the teachers decided that students would use both compass and the DMS to construct geometrical figures, unlike the previous situation where only compass had been used. The question whether to keep the use of compass despite introducing DMS, was in an early phase of the implementation process raised by Bent in a meeting with Carl and other colleagues: ”May we replace compass and ruler by Cabri? Or use them in combination? Eventually, they decided to use both tools, and the particular argument used was that only competences in use of compass were tested in the yearly national written examination in Norway [2]. Anna also gave a further reason for her choice to use both tools. She wanted to build on students' experience from use of compass some weeks ahead of the DMS use. Bent and Carl decided to use the two tools quite in parallel. In subsequent mathematics lessons, they often did similar constructions with compass in one lesson and with DMS in the next lesson. Thus, all students' had some fresh experiences from use of compass before using the DMS.

Although the national curriculum in Norway does not mention DMS use, none of the teachers seemed to have considered lack of such statements in the curriculum as a barrier for their implementation. They rather argued that the mathematics involved with the new tool was relevant, and Carl argued that the prepared instructional material they intended to use in DMS-lessons "covered most of the curriculum".

An issue for Bent and Carl was a missing possibility *to test students' learning outcome* of the DMS-use. They referred to the yearly national written examination in mathematics at grade 10 where students' competences in using DMS were not tested. Further evidence that testing with respect to implementation of the new tool was an issue of particular importance for them, is the following statement from Bent ahead of their initial use of the tool: "The yearly written examination test must reflect the teaching". In fact, the test issue was addressed at their school. Bent, Carl and David designed and used both a DMS-test within the year and another DMS-test in the local written yearly examination at grade 8. As already commented in the previous section, Bent very happily reported that students' achievements in mathematics had improved with reference to results in the DMS-test and in the geometry topic test.

Early in the implementation process, *lack of frequent access* to computer equipment was discussed as critical for the teachers' implementation. However, through their conversations with school leaders, access for their students was prioritised and early bookings of portable computers and computer labs were made. A different access issue was *students' lack of free access* to the particular DMS-software used initially, Cabri Geometry. Bent and Carl were frustrated concerning students' missed opportunity to engage with the tool at home. One year later the teachers decided to exchange the DMS-package from Cabri Geometry with the freely accessible tool GeoGebra and the issue had been solved.

Anna's implementation of the tool was mainly a single person's job while Bent and Carl worked on the implementation together with David. In an early phase of the implementation process, Bent and Carl were unsure whether they would be able to use the new tool because a local rule at their school said that all students at a grade should have similar teaching and use the same tests. Bent stated this rule in the following way: "At our school we want our students to get similar teaching and use the same tests at each grade". Only two of the three mathematics teachers at grade 8 were part of the project, but quite early they reported that David had been convinced and accepted to use the tool, the prepared instructional material and the DMS-tests they intended to design.

The issues brought up and addressed by the teachers correspond with issues reported in earlier studies (cf. Crisan et al., 2007; Goos, 2005). Compared to previous research, the most particular issue results from School 2´s rule with similar teaching and same tests, and is also a major difference in issues between the two schools in this study.

Discussion

This paper has outlined reasons and issues involved in two types of teachers' implementations of a DMS-tool. In this final section, Leont'ev's terminology *activity*, *actions* and *operations* (cf. Kaptelinin, 1996), and the notion of *activity systems* (cf. Engeström, 1999) are used in a discussion of the findings. Activity theory considers the role of a motive accomplished through human actions. I argue that teachers' *reasons*, why they decided to implement the tool concerns the teachers' goals resulting in actions, while the *issues*, how, concern what possibly prevented their actions. I argue that these theoretical constructs contribute in globalising the local findings, and give insights into the complexity involved when teachers want to use a new tool in their mathematics teaching.

Bent and Carl wanted themselves and their school to be involved in doing "new things" in mathematics teaching resulting in better learning possibilities and test results for their students. They appeared to be trigged by media statements giving the impression that Norwegian mathematics teaching is old fashioned. These ambitions indicate that the motive for their desired activity (cf. Kaptelinin, 1996) was improved students' mathematics performance through collective use of DGS at grade 8. Anna's situation was different since her school only had one mathematics teacher at each grade, and her overall motive was more personal: dare to use DGS and students' investigation of the DGS tool. The teachers shared a desired outcome of improved student performance, but with the difference that Anna's concern was on the working process of her students' investigations with the tool while Bent and Carl in addition with strength emphasised improved results in tests as a crucial desired outcome from the DMS-use.

Teachers' ways of addressing issues in order to achieve the motive of the activities is by me considered as *goal directed actions*, the second dimension suggested by Leont´ev. Anna needed to spend time on her own development with the tool as an action to achieve her goal: dare to use the digital tool in teaching and let the students explore mathematics with the tool. Bent and Carl´s actions appeared to be led by a goal that all the grade 8 classes worked in a similar way with the tool and students' performance with the tool was tested. Their actions to achieve this were to reserve more time in teaching for the topic, using prepared instruction material to avoid spending too much time and through this achieving the goal of similar teaching. They also designed their own DMS-tests to be able to judge students' performance with the DMS in geometry.

Leont´ev sets the *operation within the conditions* for the activity as the third dimension to consider (Leont´ev, 1978). This is not the main focus of this paper since the empirical data for this paper has been restricted to the implementation phase and not the actual use of the tool, where details of organisation and the work would have been captured. However, the findings indicate that teachers' concern for this level of the activity was kept in mind during the implementation process. Anna wanted an environment where the students could collaborate with tasks in their exploration of the tool, while Bent and Carl planned to use a prepared instruction material.

Use of the construct *activity system* (cf. Engeström, 1999) makes it possible to further theorise differences in the two kinds of implementation. Anna, the *subject*, was alone as the driving force for the implementation at School 1. *Division of labour* was not changed due to her implementation process, where collaboration was limited to collaboration with teachers teaching other subjects than mathematics at the grade. These teachers, other project teachers and didacticians were part of the *community* at School 1 but not actively involved in the implementation process. The *object* was implementation of DMS-tool closely in time after use of compass related to requirements in geometry in the national curriculum, and where the new DMS-tool and tasks were the *mediating tools*. For Anna, implementation of the new DMS-tool as well as her *desired outcome* to dare using DMS and students' investigation of the DMS-tool were key issues.

For Bent and Carl's implementation an important difference, compared to Anna, was that the *subject* were all the three mathematics teachers at a grade. Another clear difference concerns the large number of *rules* in their teaching activity system compared to Anna's. On an overall level, they all considered the curriculum and yearly national examination and need for reserving extra time for the geometry teaching due to this new tool. In addition, for Bent and Carl also the local rules of similar teaching in all classes at a grade and testing of the outcome of all teaching were important. These differences in rules also influence the *division of labour*.

Similar teaching meant that implementation of a new tool at School 2 needed to include all the mathematics teachers at a grade. The *community* was different from Anna's community in that the mathematics teachers at a grade collaborated. The *desired outcomes* for Bent, Carl and their colleague were improved results in geometry tests and god results on tests with DMS, which were very different from Anna's desired outcome. However, the *objects* and *mediating tools* were quite similar at two schools but with a minor difference in that Bent and Carl wanted a more coordinated use of compass and the DMS compared to Anna who wanted to build on students' earlier experiences with compass.

Conclusion

This paper is contributing to an empirical understanding of why and how teachers implement digital tools in mathematics teaching.The paper has also given a theoretical contribution with elaboration and use of cultural-historical activity theory in the context of mathematical teaching development. By using theoretical constructs such as *activity*, *motive*, *action*, *goal* and *activity system*, originating from the work by Leont'ev and successors (Leont'ev, 1978, 1981; Kaptelinin, 1996), details and differences in implementation processes of a DMS-tool have been captured and described.

The study shows that although the object at the two schools concerned the same new DMS-tool at grade 8, big differences were found in what teachers wanted to achieve and addressed in the implementation process. This brings the line back to Leont'ev's distinction between the collective activity depended on a collective object and actions building on personalised goals (cf. Kaptelinin, 1996; Leont'ev, 1978, 1981). In this paper it has been argued that indications of the different goals were visible throughout teachers' actions, what they valued in the implementation process and in the desired outcomes.

Secondly, many issues involved in an implementation process of a new digital tool have been reported in this paper. Most of these issues have been found and reported widely (cf. Crisan et al., 2007; Goos, 2005). Additionally, the study has shown how different kinds of collaboration between teachers contribute to different implementation processes. At the school where collaboration mainly was between *same school subjects teachers* at the same grade, similar teaching and use of the same tests supposed to reflect that all teaching was vital to address in order to have any implementation of a new tool at all. At the school where collaboration mainly was between *different school subject teachers* at the same grade, the implementation process became a personal matter for the teacher.

The findings document that the teachers at the school with same school subject collaboration had a more composed implementation process than the teacher from the school with different school subject collaboration. A possible consequence is the following: For schools such as School 2, a composed implementation is needed which possibly prevents development in teaching. In schools such as School 1, single school subject teacher more rapidly can change and develop the teaching based on their single initiatives. However, schools with close school subject collaboration at a grade have better possibility for sustainable development within the school since the development involves several teachers and structured changes like the content of the teaching and tests at School 2. These findings and reflections are basically in line with statements by Tondeur et al. (2008), who argue for the importance of involving many teachers in order to have implementation of digital tools and sustainable development in schools. Researchers have also argued that involvement of school and technology leadership are of crucial importance for technology integration (cf. Tondeur et al., 2008). For both schools in my study, school leaders had contributed by promoting rules for collaboration between teachers, access to equipment, and the schools' participation in professional development. Thus, the school leaders were an important part of the community, giving direction for rules and division of labour, but appeared not to be central in the actual implementation process of a given tool such as a DMS-tool package in mathematics teaching.

Thirdly, what can be said about possible consequences for students' opportunities to engage with mathematics based on the different implementation processes? I argue that the different desired outcomes, with a main emphasis on respectively students' investigation of the new tool versus improved results in common written geometry tests and good results on separate tool tests, indicate differences in what the teachers intended to emphasise in their teaching.

Finally, in the reported study the tool being implemented was a DMS digital tool. What does this mean for the generality of the findings being reported? This paper has contributed with findings indicating that the design of school collaboration with different or same school subject groups of teachers are of absolute important for the kind of implementation, issues dealt with and the possible sustainability of the use of a new tool. Thus, it can be argued that this study contributes with findings relevant for initial implementation of any tool in mathematics teaching beside some specific issues related to the particular DMS-tool.

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Notes

1 The term "didactician" is used intentionally to emphasise that both teachers and university educators can be researchers.

2 From spring 2015, the national written yearly examination in mathematics at grade 10 in Norway demands use of a "graph drawing tool" where Geogebra, Texas Instruments TI-Nspire CAS, Casio ClassPad 400 and Scientific Notebook are presented as examples of such tools on the Norwegian Directorate for Education and Training (see: http://www.udir.no/Upload/Eksamen%20endringer/Informasjon%20om%20revidert%20eksamen-sordning%20i%20matematikk.pdf?epslanguage=no).

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