ESTABLISHING DIDACTICAL PRAXEOLOGIES: TEACHERS USING DIGITAL TOOLS IN UPPER SECONDARY MATHEMATICS CLASSROOMS

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This paper discusses elements of the didactical work of ordinary mathematics teachers using digital tools. The upper secondary school in Norway where the data was collected has run an internal project to integrate the Personal Computer into the mathematics classroom. Using the Instrumental Approach as a framework this paper seeks to describe and interpret elements of teacher practice exploring also the notion of instrumental genesis from a teacher perspective. From the analysis of classroom observations, interviews, meetings, and study of documents three main didactical practices were found to be linked to the introduction of the digital tools: the digital notebook, the digital textbook, and the phenomenon of weaving between tools/instruments in the classroom.

INTRODUCTION

The recent school reform in Norway, Knowledge Promotion 2006, formally acknowledges digital competence as one of the five basic skills students should acquire and develop in their formal schooling[1]. This places on schools and individual teachers a responsibility to integrate these tools into classroom practice. This study looks at the practice of two teachers in a comprehensive upper secondary school in Norway who have been using digital tools over a period of five years. In 2007 the school joined the project "Learning Better Mathematics", hereafter LBM[2], a developmental project initiated by school authorities through a co-operation with University of Agder. Data used in this paper was collected at the school's point of entry to the project. The classrooms observed were equipped with a blackboard and a projector with screen and set up as "paperless" environments where all students had their own laptop PC and when observed rarely used paper and pencil in their mathematics lessons: all student work was done on the computer.

THEORETICAL FRAMEWORK

The theoretical approach employed emerged in the mid-nineties in France when researchers became aware that traditional constructivist frameworks were inadequate in the analysis of CAS environments (Artigue, 2002). Artigue claims that this approach is less student centred but provides a wider systemic view also giving the instrumental dimension of teaching and learning more focus (Artigue, 2007). The

[1] Knowledge Promotion (Kunnskapsløftet 2006). These basic skills are given as the ability: to express oneself orally to read, to do arithmetic, to express oneself in writing, to make use of information and communication technology

[2] The project is supported by the Research Council of Norway

approach uses notions both from the Theory of Instrumentation from the field of Cognitive Ergonomy, and from the Anthropological Theory of Didactics (ATD hereafter) in the field of Mathematics Education (Laborde, 2007).

Cognitive Ergonomy considers all situations where human activity is instrumented by some sort of technology. The theory of instrumentation employs the notion of "instrument" and the notion of "instrumental genesis" (Artigue, 2002). The instrument has a mixed identity, made up of part artefact and part cognitive scheme. It is seen as a mediator between subject and object but also as made up of both psychological structures, called schema which organise the activity, and physical artefact structures such as pencil, paper, or digital tools (Béguin & Rabardel, 2000). For the individual user, the artefact becomes an instrument through a process of instrumental genesis which involves the construction of personal schema or the appropriation of socially pre-existing schemes (Artigue, 2002). This process of instrumental genesis has two elements, *instrumentalisation* the process whereby the user acts on the tool shaping and personalising the tool, and *instrumentation* the process whereby the tool acts on the user shaping the psychological schema (Rabardel, 2003). Instrumental genesis is a process occurring through the user's activity through participation at the social plane. Guin and Trouche (1999) applied the Theory of Instrumentation in research in mathematics classrooms, studying the process by which the graphic calculator becomes an instrument for the students to learn mathematics. They term the teachers' role in guiding the students' instrumental genesis *instrumental orchestration*. This is defined as a plan of action having four components: a set of individuals, a set of objectives, a didactic configuration and a set of exploitation of this configuration (Guin & Trouche, 2002, p. 208).

ATD on the other hand aims at the construction of models of mathematical activity to study phenomena related to the diffusion of mathematics in social institutions, see for example (Barbé, Bosch, Espinoza, & Gascón, 2005). The theory analyses human action including mathematical activity by studying *praxeologies*:

> But what I shall call a praxeology is, in some way, the basic unit into which one can analyse human action at large. (Chevallard, 2005, p. 23)

Any human praxeology is constituted of a practical element (praxis) and a theoretical element (logos). The praxis has two components, the task and the technique to solve the task. The logos also has two components, the technology (or discourse) and the theory which provide a justification for the praxis.

Mathematical knowledge in an educational institution can be described in terms of two types of praxeologies: mathematical praxelologies and didactical praxeologies. The object of the didactical praxeologies is the setting up of and construction of the the mathematical praxeologies. It is these didactic praxeologies, representing teacher practice, that are of interest to me in my study. Questions arising are: What constitutes or defines the didactical task, technique, discourse and theory? How are the mathematical praxeology and the didactical praxeology entwined? How do the

existing didactical praxeologies change when digital tools are introduced into the mathematics classroom? Laborde's conclusion that, "A tool is not transparent. It affects the way a user solves a task and thinks" (Laborde, 2007, p. 142) should apply equally to both teacher and student.

Research indicates that the interventions of the teacher are critical in relation to student learning of mathematical knowledge when digital tools are introduced (Guin & Trouche, 1999). The teacher's instrumental orchestration is part of the didactical praxeology. As new tools are introduced, the teacher must develop new didactical praxeologies to support the students' instrumental genesis for the particular tool (Trouche, 2004, p. 296). The teacher must also incorporate the new tool into an existing repertoire of tools and didactical techniques. Practically in the classroom, this involves for the teacher: (1) Organisation of space and time, (2) the choosing of the mathematical tasks and the techniques to solve these tasks, and (3) the steering of the mathematical activity in the classroom by discourse.

Aim and research question

This paper aims to identify features of didactical praxeologies that have been established in relation to the introduction of the digital tool and also to describe the process of introduction of the digital tool and changes to practice from the teacher perspective. The research questions are: What features of the teachers' didactical praxeologies can be identified as pertaining to/originating specifically from the introduction and use of the digital tool? Can these features be seen as evidence of a process of instrumental genesis for the teachers in relation to the digital tool? What factors influence this process?

This short paper allows for in depth discussion of only some of the features indicated above. I have therefore selected features that appear to be of significant importance to the teachers when they describe the changing practice in relation to the tool. The paper also seeks to describe only commonalities in teacher practice.

THE EMPIRICAL STUDY

The teachers, their classes and classrooms

The two teachers in this study very generously opened their classrooms and gave of their time to this researcher. Both were active in initiating the ICT project at the school. The ICT project had been established and operated entirely within the school and was not part of any external research, design or development project. It is therefore claimed that it is the practice of two "ordinary" teachers that is described in this paper. In 2005, the school was the only school in the country to conduct final examinations in mathematics entirely on the portable PC.

This part of the study involved classroom visits to two classes of approximately twenty five students. The students were studying the subject "Theoretical Mathematics 1" (1T), which is allocated three double lessons a week, each of 90 minutes duration. These two classes were two of five classes at the school studying

this subject. Each classroom was equipped with a blackboard and a projector with screen. The screen covered part of the blackboard but it was still possible to use the blackboard. The technical features of the environment functioned without difficulties in the observation period. The classrooms observed presented as "paperless" environments as all students had their own laptop PC, leased from the school, and when observed rarely used paper and pencil in their mathematics lessons though this was permitted. All student work including exercises, notes, rough work was done on the computer. I have chosen to refer to this practice as the "digital notebook". Standard paper textbooks were no longer in use as the teachers have developed their own digital textbooks, which are made available to the students through a Learning Management System (LMS). This practice I refer to as the "digital textbook". The classrooms appeared very orderly as there were no books, papers, rulers or other items littering the desks. Each student had a PC and perhaps a bag placed on the floor under the desk. The students started work quickly plugging in and turning on the PC, contrasting sharply with "normal" classrooms where students take some minutes to find notebooks, textbooks, pencils and so on. In the observed lessons only the teachers used the projector. Student work was not displayed using the projector.

Data collection and analysis

Data collection over a period of four months involved: audio recording of an introductory meeting between the school and the university where the two teachers, a school leader, two researchers and a project leader from the university were present; lesson observation with video recording of eight lessons; audio recording of three semi-structured interviews before and after lessons with the teachers; audio-recording of seven structured interviews with students (Billington, 2008); and audio data from LBM project meetings where the teachers were present and took part in discussions. The writer was present at all events, taking field notes. In the classroom observations, researchers were present as observers, taking no active part in the planning or carrying through of the lesson. Shortly after each event a preliminary data reduction using the notes and recordings was made. Passages were also transcribed. Later all data was again reviewed, coded and further transcribed. Each data episode renders different information helping to build a picture of teacher practice identifying didactical praxeologies that would not be there without the digital tool. The meetings and interviews tell of the temporal dimension and of the changing nature of the didactical praxeologies from the teacher perspective and also reveal the institutional influences. Classroom episodes record teacher activity in the classroom revealing techniques of instrumental orchestration. Student interviews tell of the students' instrumental genesis and the teachers' orchestration from the students' perspective.

Analysis of data from meetings and interviews

The teachers were very keen to discuss the introduction of the digital tool and there were clear indications in the data that the teachers saw a process of development in their teaching practice. Examples of such comments were as follows:

Teacher 1: … and it, it has been, been of course, a long process to come this far, this software …

Teacher 2: But …there is, as such, a remarkable difference from when we started, now…

Reviewing the data from the meetings and interviews, reoccurring themes emerged. These were first categorised under three headings, justification, implementation and evaluation. I then attempted to interpret these themes in the light of the theory as presented in the table below. In a didactical praxeology, implementation would pertain to the praxis while justification and evaluation would pertain to the logos.

Justification	**Implementation**	**Evaluation**
Teachers explained why "we do what we do and continue to do what we do "	Teachers explained how they organised and carried out the project	Teachers talked about what they identified as affordances and constraints of the tool
Didactical theory – justification of practice	**Didactical tasks and techniques**	**Didactical technology (discourse) – relating theory to tasks and techniques**

Table 1: Interview Themes

The most common reoccurring themes under implementation were: the digital textbook, the digital notebook and teaching techniques in the classroom. There was also some discussion input from a school leader, which is relevant to the discussion on orchestration.

Results and discussion of data from meetings and interviews

As stated above, the teachers referred constantly to the introduction of the digital textbook and the digital notebook. Discussion of these two innovative features of the implementation occupied much of meeting and interview time. The teachers referred to the digital textbook as "Learning Book"[3]. This digital textbook has replaced the usual paper textbook that students would normally buy. It is made available through the functioning LMS. Commenting on the digital textbook, the teachers explained that as the project progressed they found that the students preferred to read the notes that they had made rather than read the paper textbook. As a new syllabus came into force this year they decided to make their own digital textbook from scratch.

Teacher 1: Yes. Totally from scratch, just from the syllabus. Not from any textbook ….We have taken the syllabus point by point …

Teacher 2: Now we use the syllabus, and it has been extremely useful to go thoroughly into the plans and now we have to make the right choices … we feel we have to make a good deal of choices … that we make for the students …

[3] Here literally translated from the Norwegian "læringsbok"

The teachers have been provoked to return to the mathematical goals in the syllabus and build from these. This development is in line with that described by Monaghan (2004). The students save this textbook to their own PC and can write in memos, and notes. All problems and exercises are also made available through the LMS for the students. According to the teachers giving out solutions on the LMS saves time that can be used to other things, for example, "we can go around and help". The students also retain these files from year to year whereas previously they sold the textbook at the end of the year. In terms of the theoretical framework of ATD this could be interpreted as a transposition of mathematical knowledge (Balacheff & Kaput, 1996) from the syllabus to a form usable on the PC.

The second innovation, the digital notebook, a notebook kept by each individual student where s/he writes and stores all notes, exercises, and rough work on his/her own PC, was also clearly important to the teachers. In fact one teacher gave this aspect some credit for the increased enrolment of girls in these maths courses.

> Teacher 1: ...and they (girls) sat on the fence for a year or so. And then a few girls signalled to the others, see here, and then the girls joined in force, ….That was when the girls saw that this was not about playing games, but this was a way to make it very nice. They got everything very systematic, got a way to keep all their notes in order, and very, very nice presentation, and this, the girls thought was very ok, and the boys too, now they have all their notes from last year and can build on this.

Choosing supporting materials for the student is a didactical task for the teacher. In this case the production of a digital textbook and the promotion of a digital notebook are clearly identifiable as innovations in relation to normal practice and could be interpreted as an instance of instrumentalisation where the user shapes the tool to his/her purpose. Data from the student interviews confirmed that these two innovations were important in the students' instrumental genesis (Billington, 2008).

This leads to the reoccurring third theme in the meetings and interviews: reflection over teaching practice in the classroom. The teachers expanded on the teaching philosophy on which they have based the project claiming that they tried to avoid the standard structure of theory, example, exercises, and method.

> Teacher 2: We have had a main principle since we started with this. These textbooks are always alike, theory, examples, and then exercises exactly like the example, and then examples that are almost the same. As far as possible we try to avoid this. Our philosophy is fewer exercises and they can rather sit and struggle with the same exercise and if it takes the whole lesson that does not matter.

Interestingly the teachers did not expose on the wonders of the digital tool per se, but rather talked of the teaching possibilities with the tool as illustrated by these quotes.

> Teacher 1: I have much more influence on my own teaching before...
>
> Teacher 1: The role of the teacher is a bit …you have greater possibilities, that is what we have seen …

> Teacher 2: But, I must say, for my sake, that I have opportunities that I would never had had without the PC.

These possibilities can be interpreted as new didactical techniques. One teacher claimed that his teaching had changed since the students have now chosen not to use the standard paper textbooks. They discussed the need to focus on understanding rather than the reproduction of algorithms. They saw the creation of the digital textbook as allowing them more freedom to steer the activities of the classroom in line with their philosophy. These reflections I interpret as discourse justifying the praxis element of the didactical praxeologies.

Choosing for students the mathematical tasks, and the techniques and tools to solve these tasks, is a didactical task for the teacher. These tools include the textbook as well as the digital tools, the software and the hardware. The nature of this didactical task has changed for these teachers in the course of the project. They have explained how previously they just followed the book, a routine, but now because of the new situation they have been forced to make new choices. They now worked together to select mathematical tasks themselves rather than following a set up in a book.

Analysis of data from classroom observation

In looking at the data from classroom observations I attempted to identify didactical praxeologies that were a result of the introduction of the digital tool. In the classroom observation data I looked at the teachers' (1) Organisation of space and time, (2) Choice of mathematical tasks and mathematical techniques and physical tools, and (3) Steering of activity through discourse, considering these to be three practical moments of the didactical praxeologies.

In the lessons observed, neither the organisation of space or time nor the choice of mathematical tasks seemed to be dependent on or unique for a classroom where the digital tool of the PC has been introduced. For example, analysis of the time disposition in lessons showed a script with recapping, homework correction, new theory, and then exercises with approximately 50 – 60 % of the lesson time spent with students working alone or in pairs on exercises. Some time however was given to the explanation of the technical aspects of performing the mathematical techniques with the digital tool. This time allocation varied from lesson to lesson.

Deviation from a standard classroom environment without digital tools was observed in the type of tools used by the students and by the teacher and also in the public discourse of the teacher. Choosing the tools for use in the lesson, for the teacher and for the students to carry out mathematical tasks is a didactical task. This is an ongoing task as choices are made in the planning but also in the conduct of the lesson. Two aspects that stood out in the observations were the manner in which the teacher used both the digital tool and the blackboard to support his/her public discourse and the manner, which the teacher referred to and talked about using the digital tool when describing the mathematical techniques to solve the mathematical

tasks. This second aspect involves a too broad discussion to take in this paper but will be discussed in the thesis of which this work forms a part.

Results and discussion of classroom observation

In the classroom observations the teachers used both the blackboard and the screen, which was connected to the PC to support their public discourse. One feature that emerged frequently in each observed lesson, I term “weaving”. Weaving describes the manner in which the teacher moved between the available tools. Three physical tools were noted to be in use when the teacher was holding public discourse: the blackboard, the PC+screen, and gestures with own body such as tracing out a curve in the air. Each of these tools is used in conjunction with the voice and schemas (cognitive apparatus). It appeared that in prepared sequences of the lessons the digital tool was used but in spontaneous situations, for example when pressed for further explanation, the teacher turned to the blackboard or to gestures.

Discussing this weaving with the teachers, one teacher explained, that “we use what is appropriate in the situation”. Teachers seemed to identify affordances and constraints of each tool. It appeared that an affordance of the blackboard was that it allowed more personal and spontaneous expression by the teacher. It may also be the case that such unplanned use of the digital tool requires a high level of skill and familiarity with the tool and as such this is a constraint of the tool. In a later instance one teacher began to draw a circle on the blackboard freehand but suddenly stopped saying; “I have an excellent tool to do this”, and then drew the circle using the dynamic geometry software on PC screen instead. Also the mathematical tasks in use were standard tasks, which could be solved without the digital tool. Had these tasks been more complex or tasks that required the use of digital tools perhaps the response of the teacher would have been different.

CONCLUSIONS AND FURTHER DISCUSSION

Returning to the research questions, three features of the didactical praxeologies as specifically pertaining to and “provoked” by the introduction of the digital tool have been identified and discussed: the digital notebook, the digital textbook, and the phenomena of weaving between tools/instruments in the classroom. The two features that are seen as particularly important by the teachers are the digital textbook and the digital notebook. These could be interpreted as examples of instrumentalisation whereby the teacher as user has adapted the tool to his/her usage. In the classroom, the observation of patterns of inter-dependent mediation between physical tools that have been adapted by the teachers, where they weave between blackboard and the digital tool in response to the situation, could be interpreted as observations of schema or expression of instrumentation as in these cases the tool which is thought to be the most appropriate is used.

Can the project implementation described above be modelled as a process of instrumental genesis for the teachers and is such a modelling helpful in gaining an

understanding of the situation? Further examination of teacher discourse will provide more information about this possible instrumental genesis process though tentative findings in this report seem to lead in this direction. Some issues to be discussed in relation to such a process are for example: the temporal dimension; if instrumental genesis is a process how is it possible to identify the different stages of this process for the teacher; and also as to which observations would indicate the formation of schema. The notion of instrumental orchestration has been discussed earlier. Is the process of instrumental genesis for the teacher also influenced by some constraining factors? Comments by the teachers indicated that, for the teachers, the process is steered in part on an organisational level by the schooling authorities at school, region, and national levels. Financial and policy support from schooling authorities is necessary for the survival of the ICT project. In the meetings, the school leader was highly supportive of the project and expressed the opinion that when students think it (mathematics) is fun, then they use more time on mathematics and so become better at it. Enrolment in mathematics has also increased dramatically. However, more important to the teachers seemed to be the response of the students. In the categories of justification and evaluation the majority of comments by the teachers concerned student learning and engagement as illustrated by the comment below.

> Teacher 1: Need to give students a challenge. Students are not educated to work in this way. Now they think it is fun. Looking for methods …

For the teachers in this study, the students' response to the new situation appears to influence the teachers' use and adaptation of the digital tool. Such comments as above also indicate that the teachers are aware of their role in orchestrating their teaching to support the instrumental genesis of the student.

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