CHALLENGES TEACHERS FACE WITH INTEGRATING ICT WITH AN INQUIRY APPROACH IN MATHEMATICS

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During more than two decades Norwegian educational authorities have promoted the use of computers, calculators, and more recently, digital tools in teaching in general in various school subjects. This paper reviews efforts to use digital tools in teachers’ and pupils’ work and problem solving in mathematics within the frame of two research and development projects in six lower secondary schools in Norway. The analysis sets out to characterise and contribute to a deeper understanding of the challenges teachers face with inquiry approach to mathematics.

BACKGROUND AND RESEARCH QUESTION

A brief history of ICT in Norwegian schools

Since 1984 educational authorities in Norway have promoted the use of Information and Communication Technology (ICT) like such as computers and calculators in schools. Some teachers and schools introduced computers on a trial basis in the 70’s, but the major effort from educational authorities came with the Stortingsmelding 39, 1983-84 (KUF, 1984) which included a four-year plan of action to implement computer technology in some selected trial schools, starting in 1984. The aim of introducing computers was to learn about computer technology in society and to use computers as a teaching aid, particular attention was directed to vocational education and pupils with special needs. A goal was to avoid introduction of new reasons to create differences between pupils. Emphasis was placed on introducing computers with software that represent new opportunities to support learning that other material or teaching aids cannot provide. A number of schools became experiment schools and were provided with equipment. Furthermore an office for coordinating and leading the effort was established on national basis. This happened at a time (1984) when micro computers were fairly new and with limited graphics, memory and processing capacity. To educate teachers for use of ICT a course of 40 hours was offered and half year courses (30 ECTS) were developed for teacher education, but the content was dominated by programming, use of databases, and limited education about teaching with ICT. The implementation of ICT as a teaching aid was not clear and purposeful. “Let a thousand flowers bloom ..” and find out what works seemed to be the idea.

The first plan of action was later followed by new strategic plans for ICT in schools, and computer technology was built into national curriculum guidelines (UFD, 2004; Krumsvik, 2007). Despite the official policy and initiatives the introduction of ICT in education has been slow in particular related to specific subjects (ITU, 2009).

In the most recent curriculum guidelines, the “Knowledge promotion” in 2006 (LK06) facility with digital tools’ was made compulsory as one of five basic
competencies and to be used in all school subjects. Furthermore, it is implied that use of digital tools will be accessible in examinations and the requirement that some test items have to be solved with computers.

**Access to and use of digital tools**

Recent surveys show that computers are now widely accessible in Norwegian schools and many pupils have their own portable computer, either private or provided by the local school authorities. On average there are 4.7 pupils per computer in primary and lower secondary schools, and 1.8 pupils per computer upper secondary schools. Internet is accessible from 90% and 98% of the computers respectively. Until recently use of digital tools, except calculators, has been limited in school subjects, and notably less in mathematics than in Norwegian, English and Social studies. This is documented in biannual reviews of technology use in schools (ITU, 2010; Arnseth, Hatlevik, Kløvstad, Kristiansen & Ottestad, 2007). Furthermore, teachers seem to be happy with learning digital competence through trying out themselves and getting guidance from colleagues.

In mathematics a spreadsheet like Excel is the most commonly used software. Dynamic geometry like Cabri, and more recently Geogebra has become popular. Internet is used like in several subjects to search information and numerical data, e.g. from Statistics Norway, (http://www.ssb.no). Drill and practice software is used to develop skills with number, perhaps most common with younger children. Recently computers have been introduced in the final examinations in mathematics in lower secondary schools, so far this is mainly the use of spreadsheets, and this raises the demands to use digital tools in teaching.

So, at the problems related to lack of equipment are mainly solved, and suitable software is available. The limited use of digital tools for mathematics teaching and learning indicates there is a challenge related to understanding and appropriate use of digital tools for teaching and learning mathematics. Related to this some questions arise: What is the role of ICT in learning mathematics? What is the nature of digital tools and how can they be utilised? This leads to the following research question related to teaching mathematics:

**Research question**

What challenges do teachers meet in teaching mathematics supported by digital tools and to provide learning experiences with an inquiry approach for their pupils to develop mathematical understanding and skills? Digital tools here are computers with open software.

The question can be divided into several sub questions related to understanding of the role of digital tools in work and learning of mathematics, challenges related to the digital tools per se or related to organising computer use integrated in the mathematics classroom. In the following I will focus on the subject oriented use of computers with an inquiry approach to mathematics. The research question will be
investigated by reanalysing/ review cases from two projects on ICT in mathematics with regard to teachers’ understanding of technology, mathematical representations and teaching approach.

THEORETICAL BACKGROUND

Teaching in general and with digital tools particularly is a complex activity for the teachers; it involves deep insight in the subject, knowledge of the digital tools, and understanding of pupils’ thinking. Furthermore, it involves pedagogical approaches and relating these to the curriculum plans and policy involved and so on, all in a dynamic changing environment. Shulman (1986) introduced the term pedagogical content knowledge, PCK, to denote the intersection of pedagogical and content knowledge in order to consider the complex interaction between pedagogy and subject content. The mathematical content and pedagogy, including the teaching approach or considerations related to teaching a specific content or subject, cannot and should not be separated. For mathematics it involves for example how to approach particular mathematical ideas and processes and make the subject accessible for pupils, to understand common errors and various ways students think about the subject. Ball, Thames & Phelps (2008) study teaching practice to understand what they call mathematical knowledge for teaching and found this knowledge is highly specialised for mathematics. The teacher needs to know more than to find a solution; they need to know various approaches and to be able to follow up pupils thinking. Mishra and Koehler (2006) extended Shulmans’ model for teacher knowledge to include technology and introduced the term technology pedagogical content knowledge, TPCK, later recast as TPACK (Koehler & Mishra, 2009). Figure 1 (from http://tpack.org/) indicates several areas of knowledge. In particular there is a need to understand and develop the knowledge related to technology and content TCK, technology and pedagogy TPK – or how technology affords new approaches to teaching, and in the centre the integration and dynamic interplay of content, technology and pedagogy, and technology (Niess, Ronau, Shafer, Driskell, Harper, Johnston, Browning, Özgun-Koca, & Kersaint, 2009)-

Introduction of technology or more specific, digital technology, in teaching implies not just learning to handle the computers with software and other digital tools, but relating the technology to the other knowledge areas, pedagogy and content knowledge. General knowledge of computer software, i.e, TK, like handling menus and keyboard commands, handling file system and even perform operations specific to the software is not sufficient. In order to develop TCK for mathematics it is necessary to understand how mathematical concepts and relations are, or can be represented within the software. Furthermore, insight is needed to realise how the software bring in new affordances and constraints related to investigation and solving mathematical problems. An example is spreadsheets where it is possible dynamically to manipulate and experiment with a whole table generated by formulae, and illustrate the distribution of values with a diagram based on the table. Spreadsheets have built in common mathematical and statistical functions and provide search and
sorting facilities. However, as pointed to by Dettori, Garuti, Lemut & Netchitailova (1995), spreadsheets have limitations with lack of symbolic manipulation and are numerical, not algebraic in nature in spite of the use of formulae for calculations. Another example of mathematical software is dynamic geometry like Cabri, Geogebra and others. After constructing a figure using built in features in dynamic geometry, part of the figure can be dragged to test if the construction is robust, i.e. not falling apart when dragging one part of the figure. A constructed figure in Cabri is not the same as a drawing which can be represented with different constructed figures in Cabri with different properties (Laborde, 1995). The order of the single constructions for composing a figure make the figure specific different from the same shape constructed in another way.

The development of deep knowledge TCK can be expressed with terms from the instrumental approach as turning the artefact into an instrument for the user (Trouche, 2005). For a specific artefact this implies to develop utilisation schemes, knowledge on the level of simple usage schemes and more elaborated instrumented action schemes. Without going in detail I find the terms helpful to indicate the depth and complexity of knowledge involved.

Mishra and Koehler (2006) point to how the TPCK framework can be used both as an analytic tool and as a tool for designing curriculum development. In particular they
point to learning by the design based on principles of learning by doing and with less emphasis on overt lecturing and traditional teaching.

RESEARCH AND DEVELOPMENT WITH ICT IN MATHEMATICS

During the last decade ICT in mathematics has been studied in several developmental research projects at the University of Agder (UiA) with close collaboration between teachers and didacticians. During the years 2001 - 2004 the ICT competence project in mathematics in lower secondary schools\(^\text{ii}\) was set out develop pupils’ competence with ICT tools so they could judge and choose for themselves which tools to use for a mathematical task, just pencil and paper or computer. Software in use was a spreadsheet, dynamic geometry and a graph plotter, and stimulating an investigative approach to teaching.

ICT and mathematics learning (ICTML)\(^\text{iii}\) ran through 2004 – 2007 in parallel with the project Learning Communities in mathematics (LCM), both with emphasis on developing a learning community with teachers and didacticians, with inquiry into mathematics and mathematics teaching as fundamental basis for the projects Jaworski, Fuglestad, Bjuland, Breiteig, Goodchild & Grevholm (2007). The projects employ a socio cultural view of learning. The pedagogical (or didactical) content of the projects emphasise pupils and teachers inquiry, to wonder and ask questions, investigate and explore and develop an inquiry attitude to teaching and learning.

ICT has also been an interest in the most recent project, Teaching Better Mathematics (TBM) (2007-2010) which build on the same fundamental principles and extend the work on ICT to upper secondary school. The projects have been concerned with how ICT can provide learning experiences for pupils through an inquiry approach to teaching and learning. Work with teachers in workshops and school team meetings to stimulate the development have been central for the development and research carried out on all areas of the work. The research methodology is developmental research (Gravemeijer, 1994) with strong interaction and integration of development and research and involved qualitative research. Methods utilised field notes, students’ computer files, video and audio recording of meetings, workshops and interviews.

SMALL CASES FROM PROJECTS

In this paragraph I will not provide the full background of the projects, but will present some episodes that can illuminate challenges teachers face as they use digital tools in their classrooms. The teachers all had some background with ICT, mainly on spreadsheets, but had hardly any experience from using ICT for mathematics teaching. (Teaching here includes providing learning experiences for pupils)

Case 1 The teacher solved the task

In a working period over a couple of weeks to summarise and evaluate the effects of the ICT competence project, the pupils were given a booklet of 10 tasks from which they could choose which tasks to work on, and whether they would like to use just pencil and paper or computers. Most students worked in pairs or small groups.
Some pupils in one class worked on the stamps task: to combine some stamps of two kinds worth 2.50 NOK and 1.80 NOK to get the value 20.40 NOK for sending a parcel (Fuglestad, 2007). Several pupils worked on simple tables in the spreadsheet to combine some of each kind of stamps adding up to 20.40 NOK. They experimented with swapping the values and how many stamps they needed. However, I observed one group of three pupils preparing a large table in Excel to make all possible combinations of number of stamps, to be sure to get all the different solutions. When I asked them to tell about their work, the pupils described their table and how they could find all the solutions. Then they commented they really did not understand, but when they asked for help the teacher, Ivar, instructed them how to make this table. Later I learned from Ivar that he made this table for himself the evening before as a preparation, and he interpreted the task to find all possible, not just one solution. The task invites to trial and error more than setting up an algorithm, and asks only for a combination of stamps, not all possible. In fact there is just one solution, but several with slight misreading of the numbers given, and so the teacher moved on to find a more general solution. Ivar seemed to think, he had to be able to present a complete solution, and when pupils asked he showed his solution.

Through his thorough preparation the teacher tells that he feels responsible to have a solution ready. When the pupils asked perhaps he too quickly provided a solution, and did not urge the pupils to investigate with sufficient time for their own solution. There is also the pressure from pupils to give help, and difficulty to know how to help except give a solution. The situation indicates the teacher put a lot of effort to solve the task, but perhaps used less time thinking of how to tackle the pedagogical task.

**Case 2 Exploring Snow man in Cabri**

Trude, a teacher at Fjellet School taking part in ICTML, decided to implement Cabri with her class of grade 8 pupils over some weeks (Fuglestad, 2010). She did not use any prewritten material but wrote the task on a flip-chart (translated in Figure 2), planned for pupils inquiry into Cabri. She gave only a short introduction to the tasks and encouraged the pupils to investigate and find out how to solve the task. The pupils were asked to experiment and find out about facilities in Cabri, including meaning and effect of some menu items and in this way build usage schemes, the simple one step operations. The pupils worked together in small groups or alone, and had opportunity to discuss their solutions with peers or the teacher. Trude wandered around and supported the pupils with questions or hints and in this way supporter their further development of Cabri as an instrument, developing their instrumented

| 1) Snow man with a stick, hanging together |
| 2) Make a figure by reflection |
| a) Reflection in a line |
| b) Reflection on a point |
| 3) $\triangle ABC$ $AB = 5$ cm |
| $BC = 4.5$ cm |
| $AC = 2.5$ cm |
| 4) Make the circumscribed circle for a triangle |

Figur 2 Task on flipover
actions schemes by combining several operations. In particular she emphasised the feature of dragging objects to test if the figure “hangs” together, in particular relevant for the Snow-man task.

Trude later presented her work in a workshop in the ICTML-project. She did not know Cabri before but was first introduced to it through the project, and worked a lot on her own to prepare before using Cabri with her pupils. She emphasised the need to learn Cabri before she “dared to use Cabri in the class”. Trude became stressed by preparing for the Cabri sessions, but also expressed great enjoyment arising from her work on Cabri with her pupils. Also on other occasions she talked about excitement over how pupils’ became engaged with investigations. Trude’s own development during the work seems related both to the technology and the pedagogy component of TPCK. The mathematical content knowledge or more precisely TCK is also affected in this as it is necessary to know the way mathematical relations are represented in Cabri.

**Case 3 Cabri and classical constructions**

At another ICTML school, Austpark, the teacher team talked about introducing Cabri, but had experienced problems to get started due to several practical obstacles. Two factors seemed to encourage their decision to implement Cabri in their classes. A course day for preparation was provided from the ICTML-project at their school and a new teacher, Jacob, started working at the school. Jacob had experience with ICT and dynamic geometry. All teachers at grade eight and two on grade nine started to use Cabri. The teachers choose to use some worksheets that were introduced by Jacob and they regarded this material to be suitable as they found it covers a substantial part of the syllabus and it was close to their own way of working (Erfjord, 2008). The material consisted of seven two-page worksheets and was structured with explanations and step by step instructions of how to carry out constructions in Cabri. The approach characterised as direct instruction with supportive comments was also observed in the teaching of classes at Austpark (Erfjord, 2008). The teachers implemented constructions using Cabri in parallel with use of compass and ruler which is the traditional way in plane geometry in schools. In addition to this convenient approach, they also argued that they expected the classical constructions to be necessary for the coming final examination for pupils. They seem not to consider other more investigative material that had been presented in a workshop in the project.

In conversations with a didactician the teachers claimed they found it difficult to be more innovative and make their own tasks. It seems difficult to both change style of teaching into an inquiry approach and introduce digital tools at the same time. Erfjord (2008) characterised this as a double innovation embedded in the project goal of ICTML. The teachers developed their competence with Cabri for mathematics, the TCK, but preferred develop their TPK close to their tradition. The reasons are understandable and reflect the pressure for curriculum, coming examination and time constraints, but also their reluctance to engage deeply to change teaching style.
Case 4 Develop material for investigation using Excel

Three teachers in Dalen school set their goal for their participation in the ICTML-project to develop their own library of Excel-tasks to complement the textbook they used (Fuglestad, 2010). The tasks would support pupils to investigate mathematical connections and properties of percentages, fractions and decimal fractions, area and volume of specific object and the like. The Excel-tasks were to support pupil’ inquiry and experiments, and follow on with support for pupils own work to prepare new spreadsheets for other tasks. During the work, tasks were tried out in the class with one or two didacticians observing together with colleagues, and later follow up with discussing experiences and further or new development in the school team which met regularly every second week. Development of the tasks challenged the teachers both on technology and on pedagogical approaches. For example with a task to investigate equal-valued fractions and display several of the same value, it was necessary to develop complicated formulae with nested if-sentences. This was solved by discussing ideas and consulting another colleague who had long experience with Excel. Pedagogical challenges like judging how complicated a comparison would look for pupils, came up after observations in discussions. The interaction between didacticians and teachers was seen useful for both parts in the development and also to stimulate the further development.

Several spreadsheet tasks was made in a similar way, with setting up an environment for the pupils to explore, to insert numbers and observe the results, discuss and experiment to find relations. The task may seem fairly directive, setting limits for investigations, directed to certain relations planned for inquiry in a limited knowledge area. However, there were also more open tasks, and tasks to develop their own set up on a spreadsheet after using the pre-made.

**DISCUSSION AND CONCLUSION**

Although the cases presented are all different they show some similarities. Some key words are: preparation, confidence and control. Furthermore: limitations in understanding of the TPCK as integrated knowledge.

The teachers feel responsibility to have a solution to the tasks they present for the class. Both Trude and Ivar put a lot of work into their preparation, solved the tasks for themselves and worked on learning the software. This is probably reflecting their wish to feel confident and in control over what will happen or feel the responsibility for having a solution at the end of the lesson. Trude expressed this as she needed to learn Cabri for her self to dare to use it in class. The pedagogical/didactical challenges related to implementing an inquiry approach with use of ICT seemed to put extra pressure on the need to prepare to feel confident.

Some teachers were reluctant to change teaching approach and therefore tried to implement ICT alongside traditional methods, to avoid large changes. Even if the teachers want to use digital tools with the resulting changes, there seems to be some deep seated traditions and external pressure that make changes difficult. At Austpart
this was expressed and commented on when they choose the teaching material that was close to their tradition, and wanted to be sure pupils also could handle ruler and compass for construction.

Also the teachers at Dalen invested a lot of time and effort to learn to use the tool, Excel, and to develop their own teaching material on file, prepare the lessons and discuss experiences and development. Reflecting on issues of control and inquiry, they seemed to find a way between the two sides, and planned for inquiry into a limited mathematical topic. On the other hand, the teachers seemed open and confident to use an inquiry approach in their classes.

As noted in the introduction of this article the process of implementing ICT tools in mathematics teaching has been slow and is still limited. Experiences in general, and from the projects points to hindrances and resistances experienced even when teachers wish to use ICT tools. Perhaps this is due to lack of understanding of what is involved in developing the technological pedagogical content knowledge, the TPCK for mathematics. Affordances and constraints are related to the various areas of knowledge as shown in Figure 1, in particular how mathematics is represented, how the pedagogy if inquiry approach can be implemented with ICT and so on. I think a study of the various knowledge areas and combination of part and in the full integration of mathematical content, inquiry approach and affordances and constraints of relevant technology would prove useful to guide further developmental research in the area.

REFERENCES


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1 ICT and digital tools will be used interchangeably
2 The ICT competence project was supported by a grant from the Department of Education to stimulate ICT in schools
3 LCM and ICTML were supported by The Research Council of Norway (RCN), TBM was supported by RCN and The Competence Development Fund of Southern Norway.
4 NOK is Norwegian crown, the Norwegian currency