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USING ACTIVITY THEORY IN RESEARCHING YOUNG CHILDREN'S USE OF CALCULATORS

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Constructivist and socio-cultural perspectives in mathematics education highlight the crucial role that activity plays in mathematical development and learning. Activity theory provides a socio-cultural lens to help analyse human behaviour, including that which occurs in classrooms. It provides a framework for co-ordinating constructivist and socio-cultural perspectives in mathematics learning. In this paper, we adopt Cole and Engeström's (1991) model of activity theory to examine the mediation offered by the calculator as a tool for creating and supporting learning processes of young children in the social environment of their classroom. By adopting this framework, data on young children's learning outcomes in number, when given free access to calculators, can be examined not only in terms of the mediating role of the calculator, but also within the broader context of the classroom community, the teachers' beliefs and intentions, and the classroom norms and the division of labour. Use of this model in a post hoc situation suggests that activity theory can play a significant role in the planning of future classroom research.

Introduction

> A fundamental assumption of activity theory is that tools mediate or alter the nature of human activity and, when internalised, influence humans' mental development. (Johassen & Rohrer-Murphy, 1999, pp. 66–67)

According to Cobb (1994), both constructivist and socio-cultural perspectives in mathematics education highlight the crucial role that activity plays in mathematics development and learning. He claims that activity theory provides a framework for co-ordinating constructivist and socio-cultural perspectives in mathematics learning.

Activity theory had its beginnings in the German philosophy of Kant and Hegel, the more contemporary philosophy of Marx and Engels, and the cultural-historical psychology of Vygotsky (see, for example, 1978) and Leont'ev (1974; 1978; 1981).

Kuutti (1997) emphasises the fact that individual actions are always situated in a meaningful context and are impossible to understand in isolation without the meaningful context as the basic unit of analysis. According to Kuuttii, an activity always contains various artifacts (e.g. instruments, signs, procedures, machines, methods, laws, forms of work organisation) through which actions on objects are mediated. Artifacts themselves are created, manipulated and transformed during the development of the activity and carry historical residue of the development. For example, artifacts are often the outcomes of previous actions on objects

(Bødker 1997). Therefore, artifacts, the goals of actions, their overall motive, and the activity itself are redefined in the course of human functioning (Engeström, 1991).

Cole and Engeström (1991) define an activity as a form of doing, which is intentional and directed towards the creation of a physical or mental object. This in turn leads to an outcome. Cole and Engeström's model of activity, as seen in Figure 1, highlights three mutual relationships involved in every activity:

- the relationship between the subject and the object of the activity, which is mediated by tools that both enable and constrain the subject's action;
- the relationship between subject and community, which is mediated by rules (explicit or implicit norms, conventions, social interactions); and
- the relationship between object and community, which is mediated by the division of labour (roles characterising labour organisation).

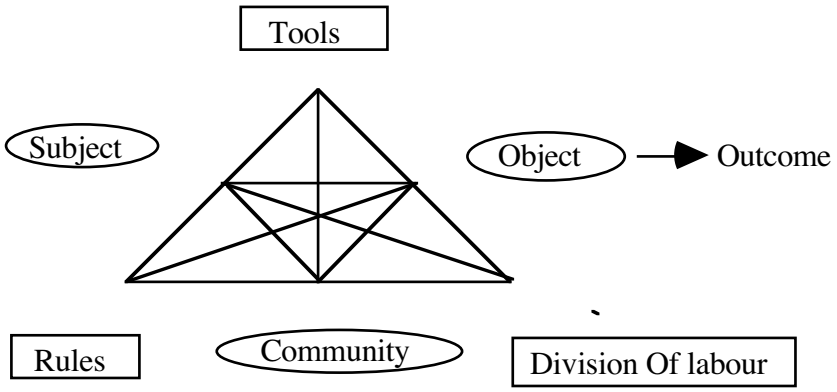

Figure 1: Cole and Engeström's (1991) model of activity

Cole and Engeström (1991) see relationships occurring between elements (the subject, the object and the community) within the activity as crucial to transforming the object into an outcome.

This paper discusses the *post hoc* use of Cole and Engeström's (1991) model of activity by one of the authors in her doctoral thesis (Dale, 2003) to examine the mediation offered by the use of a simple four-function calculator as a tool for creating and supporting young children's learning of number in the social environment of their classroom.

Calculators as a mediating tool

The focus of Dale's (2003) study was the mediation offered by a calculator as a tool for acquiring specific concepts and skills in young children's learning of number.

According to Verenikina (2004), Vygotsky's *Zone of Proximal Development* (ZPD) was initially developed for testing not only children's current level of achievement but also their potential development, with the level of assisted performance indicating a person's potential development in the near future. "Thus the zone of proximal development is the distance between what a person can do with and without help" Verenikina (2004, p. 202).

Adopting a Vygotskian framework, Pea (1985) distinguished between the potential for technology to act as a cognitive amplifier — i.e. to "change how effectively we do traditional

tasks, amplifying or extending our capabilities" — and as a cognitive re-organiser – i.e. as a tool whose use can "fundamentally restructure the functional system for thinking" (Pea, 1995, pp. 168; 170). According to Pea (1997, p.99), the fundamental question is "How can technology support and promote thinking mathematically?"

Acknowledging Pea's distinction, Salomon, Perkins and Globerson (1991) further distinguish between the effects *with* technology use — i.e. the effects while people are working with technology — and the effects *of* technology use — i.e. the "subsequent cognitive spin-off effects for learners working away from machines" (p. 2). According to Salomon, Perkins and Globerson (1991), intelligent technology — i.e. technology that is able to "undertake significant cognitive processing on behalf of the user" (p. 3) — has the potential for the formation of an intelligent partnership where the division of labour between the human and the technology allows the "partnership … [to] be far more 'intelligent' than the performance of the human alone" (p. 4). Jones (1993; 1996) proposes that, when assessing mathematical intelligence, we need to consider whether it is the performance of a student alone or the partnership that needs to be assessed.

Findings of studies into the cognitive effects of using technology have been mixed (Salomon, Perkins & Globerson, 1991, p. 6; Pengalese & Arnold, 1996). A critical factor in achieving cognitive effects *of* using technology (or Pea's cognitive re-organisation) is to provide students with situations, which require "mindful abstraction" (Salomon, Perkins & Globerson, 1991, p. 6). However, the calculator has not been specifically developed for such a purpose, but rather the purpose of solving particular problems (Jones, 1993). According to Jones (1996), the challenge to teachers is to develop instructional strategies that promote the formation of intelligent partnerships.

Pengalese and Arnold (1996) urge researchers not to treat the calculator in isolation from the context in which it is being used — the particular learning environment. Berger (1998) comments on the scarcity of research directed towards explanation and interpretation of how technology functions as a tool for learning. She states that many researchers are unable to distinguish the tool from the context and instructional process within which it is used and proposes using an interpretive framework, based on a Vysgotskian approach to learning, with emphasis on mediated activity within a particular socio-historical context as being appropriate to address the relationship between the mathematical learner and technology.

Overview of the study

The study investigated the role of the calculator as a tool for learning in the development of number knowledge of three girls and three boys during their first two years of primary schooling. The study was carried out in a school where the teachers had previously been involved in the *Calculators in Primary Mathematics* project, a long-term research project investigating the effects of the introduction of calculators on the learning and teaching of primary mathematics (see, for example, Groves & Stacey, 1998). Children in these classes had free access to calculators from the beginning of school.

A case study approach was used, with data gathered by: observing and interviewing participants over an extended period of time; administering questionnaires; and collecting relevant documents, photographs, and samples of children's work. In all, forty-one classroom lessons were observed, with each of the six children also taking part in five task-based

interviews to provide data on the development of their number knowledge over the two years of the study. Each of the two teachers completed a questionnaire on their expectations of children's number learning, and was interviewed to: establish major features of their approaches to the teaching of mathematics and changes to these as a result of using calculators; verify findings regarding the actual number achievement of the six children; and compare these findings with curriculum expectations and their own expectations.

Findings from the study showed that, by the end of their first two years of schooling, the six children had achieved high levels of understanding of number. They were working with large numbers, fractions, decimals and negative numbers, consistent with Australian and UK curriculum expectations for the end of at least three years of schooling and sometimes well beyond. However, it was clearly not possible to attribute this high level of performance solely to the use of the calculator, without taking into account the other aspects of the overall activity of learning mathematics over the two-year period.

Using activity theory as a framework

As part of the study, a great deal of data had been collected and analysed in a variety of ways. During the course of the study, it had changed from being aimed at a masters thesis to a doctoral thesis. At the time of this change, it was suggested by a member of the colloquium panel that a major feature of the thesis should be an in-depth analysis of the way in which the calculator acted as a mediating tool in the children's learning of number. However, it was not at all clear at the time of writing the thesis how best to report the research. It was only at this point that it was decided to use activity theory in an attempt to look holistically at the individual children's learning in the social setting of the classroom. Activity theory, which draws attention to mediated activity within a social context, was used to explore the relationships between the child, the calculator, the teacher and the classroom environment.

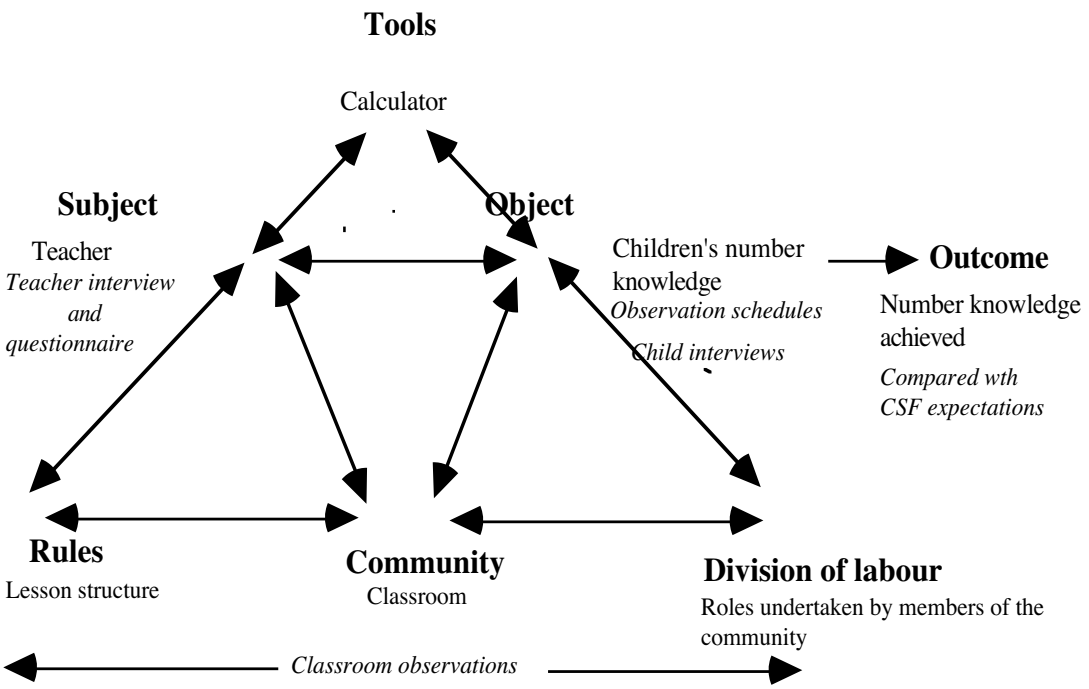

Figure 2: Applying activity theory to the study of young children using calculators

Figure 2 shows the way in which the activity theory model was applied to the study. In activity theory, the "unit of analysis is the activity, the minimal meaningful context for understanding actions" (Kuuti, 1996, p. 28). For the purpose of the thesis, the activity was defined as children learning about number with free access to calculators. The expected outcome was defined as enhanced number knowledge.

Figure 2 also shows, in plain text, the way in which the various components of the activity were defined, and, in italics, the data sources used to obtain information about each of the components.

It also shows the mutual relationships involved in the activity and their mediators as follows:

- the relationship between the subject (the teacher) and the children's learning about number (the object), mediated by a variety of materials including the calculator (the tools);
- the relationship between the subject (the teacher) and the community (the classroom setting and the school), mediated by rules (implicit and explicit conventions implied by, among other things, the lesson structure); and
- the relationship between the object (the children's learning about number) and the community (the classroom setting and the school), mediated by the division of labour (the roles undertaken by the members of the classroom community).

In reporting the details of the research, four "views" of the activity were presented, each of which is shown diagrammatically below, together with a brief explanation of the type of description involved.

The learning environment. Figure 3 shows the sections of the activity theory model used to report on the *learning environment*, together with the data sources used in the analysis.

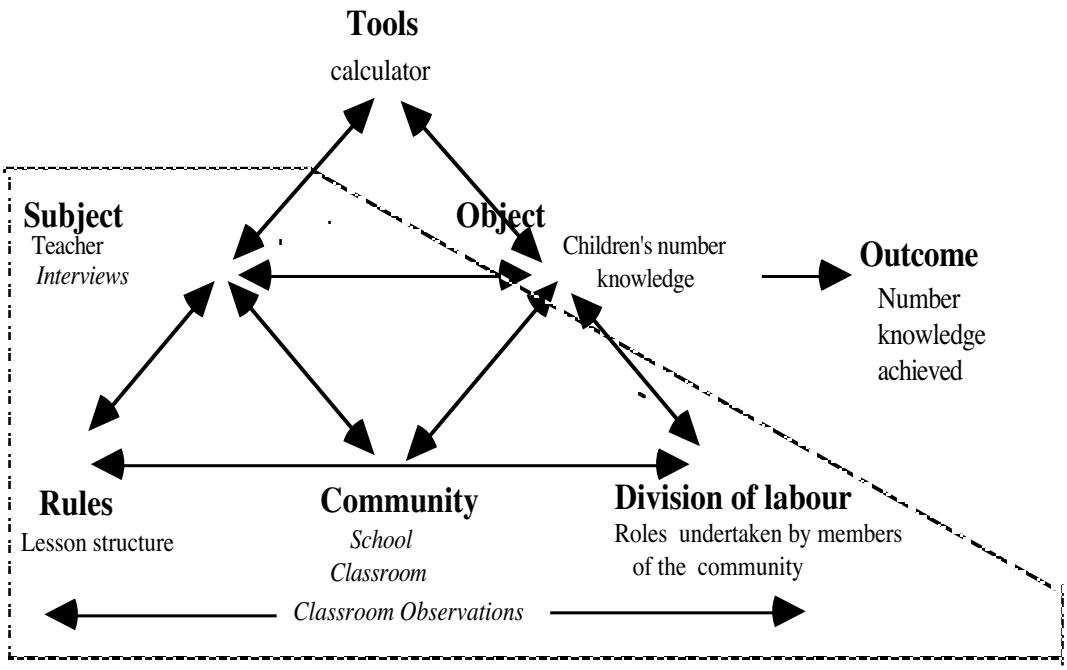

Figure 3: Sections of the activity theory model used to report on the learning environment

Portions of the teacher interviews were used to give not only background information about the teachers, but also to explore their intentions for and expectations of children's mathematical learning, as well as the changes they had perceived in their teaching as a result of their prior involvement in the *Calculators in Primary Mathematics* project. Classroom observations formed the major data source for the discussion of the community — the school, the classrooms and their organisation, and the nature of the social interactions; the rules — as exemplified by the lesson structure, which was based on an inquiry approach with a focus on independent individual and group mathematical activity with a strong emphasis on sharing of multiple solution strategies; and the division of labour — between the teacher and the children, but also between children, concrete materials and the calculator.

The role of the calculator. Figure 4 shows the sections of the activity theory model used to report on the *role of the calculator*, together with the data sources used in the analysis.

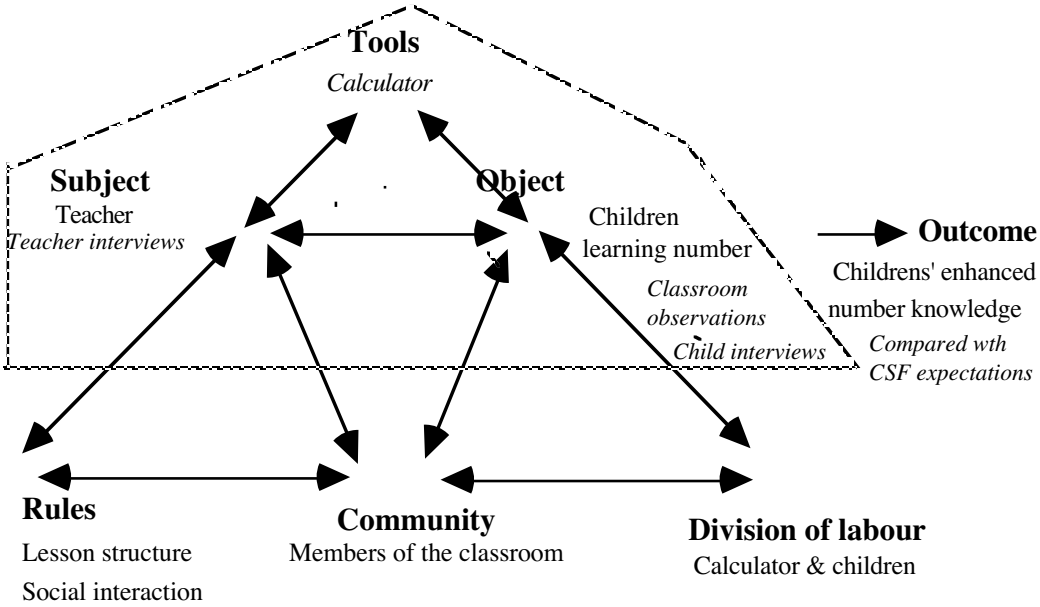

Figure 4: Sections of the activity theory model used to report on the role of the calculator

While in a sense the whole of the thesis was about the role of the calculator as a mediating tool in the children's learning of number, this section focused specifically on the ways in which the calculator was being used and evidence of their use as a *cognitive amplifier* or as a *cognitive re-organiser* (Pea, 1995). Classroom observations formed the major data source, together with a small part of the teacher interviews providing information on the teachers' views of the role of the calculator.

Twelve vignettes were used in this chapter to describe ways in which the calculator was used, and these were analysed in terms of curriculum content, different strategies used by the children to complete the tasks, the role of the calculator, and the levels of attainment indicated.

An example of such a vignette is included below as Vignette 1 (see Dale, 2003, p. 155). The lesson, which took place in February of the year when the children were in grade 1, involved children using "sharing between" for division, but resulted in some children exploring decimals in ways which could not have happened without the presence of the calculator.

FOUR COOKIES AND A CRUMB

After reading the story *The Doorbell Rang* by Pat Hutchens, the children discussed sharing equally so that everyone had the same amount. They were to asked to share a number of cookies between the 24 class members. G! chose 99 cookies as the number of cookies to be shared.

Working in groups of 4 or 5 the children were told to use whatever aids they needed to solve the task and to record the activity on paper in their own way.

G1, G3, B1, B2 and B3 chose to work together while G2 decided to work alone keying into her calculator 99 ÷ 24 = and putting her answer into the calculator memory.

B1 was chosen by the group to record their work by drawing 24 plates while the other group members keyed into their calculators 99 ÷ (shared between) 24 =. As the group members found the answer on their calculators B1 drew 4 cookies on each plate and added "a crumb" to represent 0.125 .

B1's drawing of plate twenty-four with 4 cookies and a crumb on it. Below shows how he recorded the plates drawing the cookies on each plate to show each child's share.

During sharing time the teacher asked, "How many cookies did we get?"

G1 shared how she found her answer as follows, "I pressed ninety-nine shared between (÷) twenty-four and that equals four point one two five".

G2 keyed 99 ÷ 4 = into her calculator but depended on G1 to read the answer.

B2's answer was "Four cookies and point one two five". Then he asked, "What's point one two five? I know we will get 4 and a bit each".

B3 said "I pressed nine and nine again then shared between (÷) and I pressed twenty-four equals and it says four point one two five. That must be four cookies and a crumb. I know point five is a half, point two five is a quarter and point seven five is three quarters, but I haven't come across point one two five before".

Using their calculators the children found out that if 2 children had 4 biscuits each that would be 96 biscuits (24 x 4) and 3 were left over. To share the 3 left over between 24 , B1 drew the 3 biscuits and showed there were 6 halves saying, "That's not enough pieces". B1 then drew lines again to cut the half biscuits into half saying, "That's only 12 pieces". B2 commented "a half of a half is a quarter".

B3 tried drawing lines to cut each quarter in half and found each cookie was in 8 pieces. The children counted the 8 pieces in each cookie. B3's response was "that's 24 pieces altogether and each piece is one eighth". He explained that "point one two five must be an eighth of a cookie' and that each child got 4 and an eighth of a cookie and that was the same as 4.125 cookies each".

(Source: Classroom observation 20, February 1994)

Vignette 1: Four cookies and a crumb (Dale, 2003, p. 155)

Learning outcomes for the children. Figure 5 shows the sections of the activity theory model used to report on the *learning outcomes for the children*, together with the data sources used in the analysis.

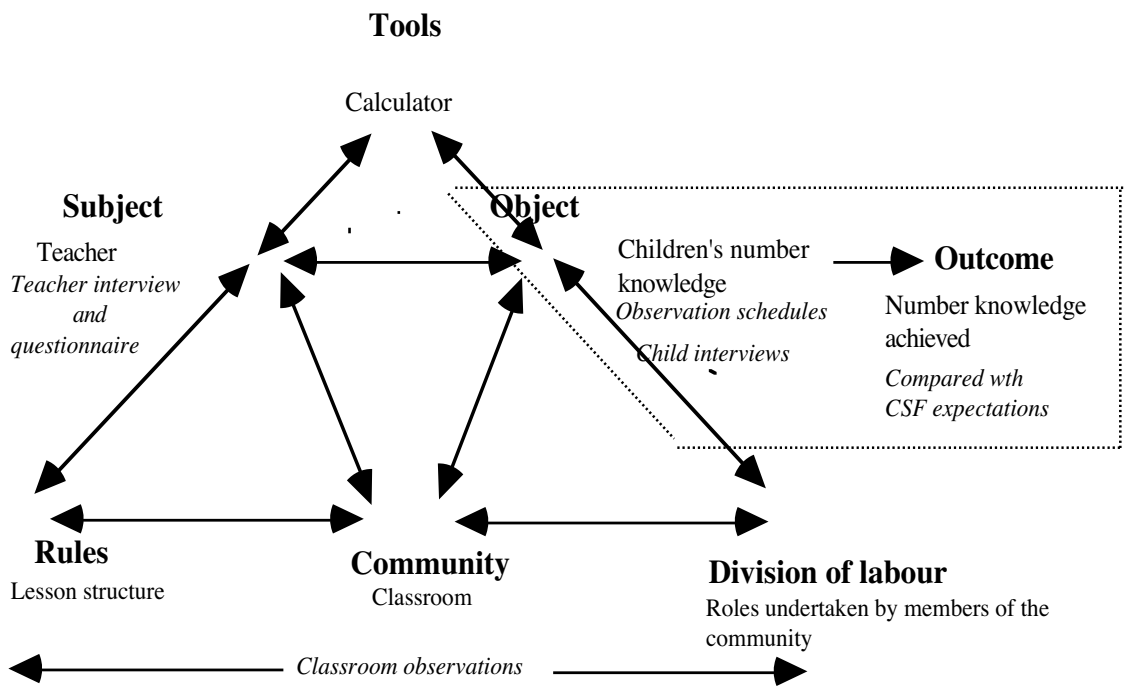

Figure 5: Sections of the activity theory model used to report on learning outcomes

The extensive data from the five interviews with each of the children formed the main source of data for the discussion of the children's learning outcomes in number. These were compared with both the learning demonstrated in the observed lessons and the expectations of the *Curriculum and Standards Framework: Mathematics* Board of Studies, 1995).

Teacher perceptions of the children's learning. Figure 6 shows the sections of the activity theory model used to report on the *teachers' perceptions of the children's learning*, together with the data sources used in the analysis.

Part of the information related to the teachers' perceptions of learning outcomes for the children in prep and grade 1, based on their responses to a questionnaire previously used in the *Calculators in Primary Mathematics* project. The teacher questionnaire was used at the beginning and end of year to establish teacher expectations of the children's performance on various items. Further information was gathered from the teachers' responses in an end-of-year interview used to establish teachers' perceptions of how calculators had made a difference to their classroom practice; reasons for changes in their expectations of children's performance; the extent to which the findings related to the children's learning outcomes mirrored their experience; and the degree to which they believed the six children in the study were representative of the class.

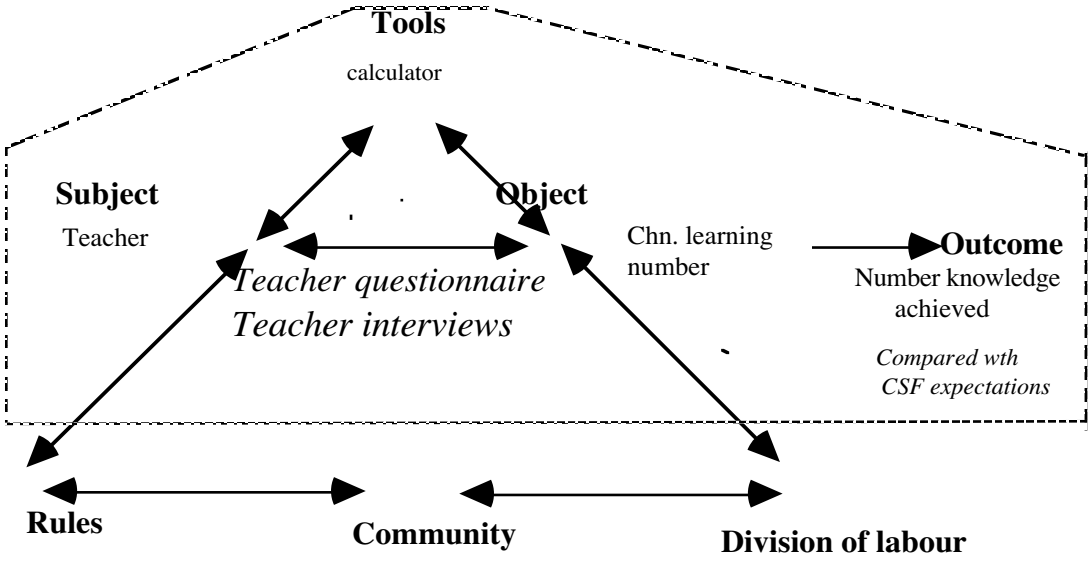

Figure 6: Sections of the activity theory model used to report on teacher perceptions of children's learning

With hindsight

In the case of the research reported here, activity theory was used in a *post hoc* way to provide a convenient and appropriate framework for organising the reporting of research that had already taken place. With hindsight, it would have been a good way to frame the research from its beginning.

The teachers in whose classrooms the research took place had participated in the *Calculators in Primary Mathematics* project in the three years before the research reported here. That project, which involved a total of 79 prep to grade 4 teachers and approximately 1000 children in six Melbourne schools during the period 1990–3, focused not only on the effect of calculator use on children's learning of mathematics, but also on their teachers' classroom practice. Clarke and Peter's (1993) model of teacher professional growth was used as a basis for explaining teacher change (see, for example, Groves, 1993). Project teachers identified many changes in their mathematics teaching — common changes included mathematics teaching becoming more "open-ended", increased knowledge of children's conceptual development; mathematics teaching having become "more like language teaching"; more discussion and sharing of mathematics; and more use of inquiry and problem solving.

Nevertheless, anecdotal evidence shows that the use of calculators was not necessarily sustained after the *Calculators in Primary Mathematics* project ended, with even the most committed and competent teachers saying that calculator use had waned substantially. With hindsight, it seems clear that we paid attention only to the "top half" of the activity theory triangle, without paying attention to the other components. Moreover, we had not taken into account some of the "principles" of activity theory: that activity systems should be the prime unit of analysis; that an activity system always comprises multiple points of view, traditions and interest; that activity systems can only be understood against their own history; the central role of contradictions as sources of change and development; and the possibility of expansive transformations in activity systems (see, for example, Engeström, 1999).

With foresight, it appears that activity theory can play a significant role in the planning of future collaborative classroom research aimed at envisioning and implementing new practices that take into account the constraints and affordances inherent in the activity system as a whole.

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